HANDBOOK OF MANURES AND FERTILIZERS

Table for Imperial to Metric Conversions

Multiply	of ———→	to	Multiply
by	to ←———	of	by
	Linear Measures		
0.394	Inches	Centimetres	2.54
3.281	Feet	Metres	0.305
1.094	Yards	Metres	0.914
0.621	Miles	Kilometres	1.609
	Square Measures		
0.155	Square inches	Square centimetres	6.452
10.764	Square feet	Square metres	0.093
1.196	Square yards	Square metres	0.836
2.471	Acres	Hectares	0.405
0.386	Square miles	Square kilometres	2.590
	Cubic Measures		
0.061	Cubic inches	Cubic centimetres	16.387
35.315	Cubic feet	Cubic metres	0.028
1.308	Cubic yards	Cubic metres	0.765
	Weights		
15.432	Grains	Grams	0.065
0.035	Avoirdupois ounces	Grams	28.350
0.032	Troy ounces	Grams	31.104
2.205	Avoirdupois pounds	Kilograms	0.454
1.968	Hundredweights	Quintals	0.508
	Concentration		
0.160	Ounces per Imp. gallon	Grams per litre	6.236
0.134	Ounces per U.S. gallon	Grams per litre	7.490
	Yields		
0.892	Pounds per acre	Kilograms per hectare	1.121
89.218	Pounds per acre	Quintals (dz) per hectare	0.011
0.008	Hundredweigths per acre	Kilograms per hectare	125.54
0.796	Hundredweights per acre	Quintals per hectare	1.255
0.089	Gallons per acre	Litres per hectare	11.21

Adapted from *Fertilizer Use—Nutrition and Manuring of Tropical Crops* by courtesy of Verlagsgesellschaff für Ackerbau mbH, Hannover.

HANDBOOK OF MANURES AND FERTILIZERS

(REVISED EDITION)

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PREFACE

THE LOW YIELD of crops in India as in many other countries following traditional methods of farming are largely due to poor fertility of the soil, caused by the progressive depletion of the plant nutrients through crop growing, soil erosion and leaching in areas of excessive rainfall. Extension of irrigation without simultaneous programme of maintenance of soil fertility merely leads to soil impoverishment before long. Although the need for the replenishment of soil fertility for higher level of crop production is growing day after day because of the growth of human population, inadequate attention continues to be paid to this important aspect of soil management. Dung, which is well known for its soil-ameliorating effect, is burnt in many parts and is not properly conserved for return to the land.

Considerable progress has been made abroad to develop measures for improving soil fertility through the use of organic manures and inorganic fertilizers. Even bacterial fertilizers have been developed in recent years. These developments have influenced the fertilizer industry on the one hand and the formulation of scientific principle of manuring and fertilizer-use on the other, resulting in the use of fertilizer and manure on an ever-increasing scale. Levels of crop production reached by different countries are positively correlated with their inputs of fertilizers and manures.

In India, too, the importance of manures and fertilizers for increased production has been amply justified by the results of a large number of experiments conducted at the Government Farms but more particularly by trials on cultivators' fields.

Recognizing the importance of the fertilizer-use, based on studies in the country, it has been planned to increase their availability in the country through local production and imports. There are proposals to increase the production and the consumption of fertilizers further during the Fourth and subsequent Plans. The increased availability of the fertilizer resources is, however, only the means to the end, and the desired results in crop production will accrue only if these resources are used in a judicious manner based on the results of research carried out in the country.

The Indian farmer, as is true of farmers of some other countries, is not fully conversant with the methods of improving soil fertility and the judicious use of fertilizer. Sound principles of manuring and fertilizer-use must be introduced in farmers' practices as early as possible to increase his income and fulfil the national objectives of self-sufficiency in the basic needs. This is only possible if the knowledge gained through research and experimentation is brought home to the growers by the normal extension agencies employing the established methods of extension.

Need was, therefore, felt to compile the available information on manures and manuring and present the same in the form of a handy but comprehensive compendium, to serve as a basis for disseminating the information to the farmers. The *Handbook of Manures and Fertilizers* is an attempt in this direction. It contains useful information on the ways of increasing manurial resources, the different kinds of manures and fertilizers, their composition, their role in the nutrition of crops, methods and time of their application and related topics such as liming and use of micro-nutrients, for increasing the yield of field and horticultural crops of India.

The Handbook is written by a team of specialists who have spent most of their time in studying the problems of soil fertility and the use of fertilizers and manures as a measure for stepping up crop production. Besides being useful to the farmers and the extension workers it is expected to be a valuable source of information to the students of agricultural colleges and all those who are interested in knowing more about manures and fertilizers in relation to crop production. Although the book has been written primarily for India, the principles dealt with are expected to find a wider application.

J. S. PATEL

Former Agricultural Commissioner with the
Government of India

CONTENTS

Page

PREFACE 5

I. ROLE OF PLANT NUTRIENTS IN CROP PRODUCTION 11
Nutrients; Function of Nutrients in Crop Growth; Nutrient Supply and Crop Growth; Deficiency Symptoms.

II. SOILS AND CLIMATE 34
Soils.

III. GREEN MANURE 47
Green Manure Crops; Green Leaf Manuring; Techniques of Green Manuring; Response of Crops to Green Manuring; Residual and Cumulative Response to Green Manuring; Components of Green Manuring; Addition of N through Green Manuring; Effect of Green Manure of Soils; Place of Green Manure in Rotations.

IV. ORGANIC MANURES (OTHERS) 68
Farmyard Manure; Composition; Decomposition; Value and Functions; Method of Preparation; Use and Effect; Artificial or Synthetic Farmyard Manure; Compost; Nightsoil and Sewage; Biological Fuel Gas and Slurry; Oilcakes; Bones and Bonemeal; Fish Manure; Guano; Other Manures; Nightsoil and Urine; Construction and Use of Latrines; Nightsoil Compost.

V. FERTILIZERS 123
General; Nitrogen Fertilizers; Phosphatic Fertilizers; Potassic Fertilizers; Other Fertilizing Materials; Fertilizer Mixtures; Quality Control; Marketing and Distribution; Valuation of Fertilizers.

VI. MICRONUTRIENTS 160
Role in Plant Metabolism; Effects of Microelements; Zinc; Manganese; Copper; Iron; Boron; Molybdenum.

Page

VII. APPLICATION OF FERTILIZERS 195
Principles of Efficient Utilization; Methods of Application; Time of Application; Spraying of Fertilizer Solutions.

VIII. SOIL FERTILITY ASSESSMENT BY SOIL-TESTING SYSTEM 211
Soil Fertility; Soil Testing; Soil-testing Kit.

IX. SOIL INOCULANTS—BACTERIAL AND ALGAL .. 222
Bacterial Inoculants; Culture; Growing of Micro-organisms on Mass Scale; Algal Inoculants; Blue-green Algae Capable of Fixing Nitrogen; Sea-weed as Manure.

X. SOIL AMENDMENTS 253
Acid Soils and Their Amendments; Lime; Amendments for Alkali Soils; Soil Amendments in Saline-alkali Soils; Gypsum Requirements of Soils.

XI. MANURING OF CROPS 275
Manuring of Horticultural Crops; Fruits; Vegetables; Manuring of Field Crops; Paddy; Wheat; Barley; Maize; *Jowar*; *Bajra*; *Ragi*; Pulses; Groundnut; Castor; Sesamum; Linseed; Rape and Mustard; Cotton; Jute; Sugarcane; Potato; Tobacco; Fodders and Grasses.

APPENDICES 341

REFERENCES 367

INDEX 381

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CHAPTER I

ROLE OF PLANT NUTRIENTS IN CROP PRODUCTION

Several elements take part in the growth and development of plants, and those absorbed from the soil are generally known as plant nutrients. Besides these, the plant takes up carbon, oxygen and hydrogen, either from the air or from the water absorbed by roots. For instance, a corn plant absorbs more than 38 elements, and other plants may absorb more than this number. These elements serve as raw materials for growth and development of plants, and formation of fruits and seeds.

The seed contains the germ which develops into a plant. When placed in the soil the seed absorbs water and the germ utilizes the stored food in the seed for its germination and initial growth. Usually the quantity of food stored in the seed is very small and just enough for the primary root to force its way into the soil and the shoot to emerge into the atmosphere. Both these organs then begin to absorb food from the soil and atmosphere respectively. Two types of soils are met with in nature, namely (*i*) the mineral soils, and (*ii*) the organic soils. The former contain 90–99.8 per cent of minerals. The latter contain organic matter as high as 70–80 per cent, the mineral fraction being only 20-30 per cent. The mineral soils develop from the weathering of rocks by chemical, mechanical or biological agencies. The organic soils originate from an accumulation of large quantities of organic residues of water weeds in marshy areas. The origin of these types explains the difference in the composition of these categories of soils. Most of the essential elements are found in liberal quantities in the mineral soils. In spite of the fact that these are available in plenty, these may not be available to the plants, as they are tied up in chemical compounds. The roots cannot absorb and deliver them to the growing plants for synthesis, and hence, the need for meeting deficiency by application of manures and fertilizers to such soils for optimum crop production.

NUTRIENTS

Although plants absorb a large number of elements, all of them are not essential for the growth of crops. The elements are absorbed because they happen to be in the soil solution, and those taking active part in the growth and developmental processes are called the essential ones. Some of these are required in large amounts and some in traces. These are classified as major and minor nutrients, and are further classified as follows:

Major nutrients

Group I: Carbon, hydrogen and oxygen.
Group II: Nitrogen, phosphorus, potassium and sulphur.
Group III: Calcium and magnesium.

Minor nutrients

Iron, manganese, boron, zinc, copper and molybdenum.

It has been found that the presence of some elements which are not considered essential for plant growth and are not directly concerned in the nutrition of the crop, but are present in the plants used as food and feed, are of vital importance to the health of man and animals. The elements within this group are chlorine, iodine, cobalt and sodium. In addition, there is another group of elements which are toxic to the animals feeding on the plants containing them. These are selenium, lead, thallium, arsenic and fluorine. Elements, such as sodium, chlorine, fluorine, nickel, lead, arsenic, selenium, aluminium and chromium, when occurring in soils in high available amounts, may also prove toxic to the plants and restrict their growth.

Some elements, occurring freely in the soil, are absorbed by the plants as impurities. They may occasionally stimulate growth although they are not essential for plant growth. They include lithium, strontium, tin, radium, beryllium, vanadium, barium, mercury, silver and bromine.

Major nutrients

Carbon: Plants absorb carbon from the atmosphere as carbon dioxide. Atmosphere contains approximately 3 parts per 10,000 parts by volume of carbon dioxide. It is readily available to the plants for the manufacture of sugars and other plant products. In fact, plants in the process of respiration give out considerable amounts of carbon dioxide, which replenishes the gas in the atmosphere and keeps the amount of carbon dioxide fairly constant.

The concentration of carbon dioxide in the soil atmosphere varies from 0.12–2.5 per cent by volume. The carbon dioxide present in the soil atmosphere is not absorbed by roots. The exchange of oxygen and carbon dioxide from the plant roots due to respiration in these organs is a constant feature. Excess carbon dioxide in the soil atmosphere escapes into the air.

The organic matter, during its decomposition, also gives out carbon dioxide. Other products, like wood, coal, gasoline, etc., on combustion evolve carbon dioxide. Owing to these replacements a constant flow of carbon dioxide is maintained in the air and is made readily available to the plants for their growth processes.

Hydrogen: Water, which contains two parts of hydrogen and one part of oxygen, is the source of hydrogen required for plant growth. The breakdown of water occurs within the plant, when carbon dioxide combines with water to form primary sugars. Hydrogen is an active element and cannot stay alone. When organic matter or other combustible substances decompose, hydrogen combines with oxygen to form water or burns itself to release heat. Free hydrogen, therefore, does not exist in the air.

Of the total amount of water absorbed by the plant, only a small fraction is required for the growth processes. It is this small fraction that meets the hydrogen requirement for the synthesis of food in the plant. This, availability of hydrogen for plant growth is determined by the ready availability of moisture in the soil.

Oxygen: The oxygen used by plants is obtained from various sources. When water decomposes in the body of the plant, oxygen is made available for growth and development. Oxygen is also present in the atmosphere. The aerial parts of the plant absorb oxygen from the atmosphere for the process of respiration and give out carbon dioxide in exchange. The soil atmosphere also contains oxygen and it may be as low as 2 per cent. In the cultivated soil with good aeration it is about 20 per cent of the soil air in the top 15.24 cm and decreases with depth. Sandy soils contain more oxygen than heavy or waterlogged lands.

Under normal conditions, the plants readily obtain oxygen for the process of respiration from these various sources. Under abnormal conditions, such as waterlogged soil, the plant utilizes internal oxygen. In such a situation the manufactured food in the plant decomposes and supplies the needed quantity of oxygen for the respiratory activity.

Nitrogen: Although atmosphere contains 80 per cent of nitrogen, the plants cannot directly absorb it. There is some elemental nitrogen present in the soil air but that also is not made use of by the plant. It is the combined nitrogen in the soil which is absorbed by plants through soil solution. The leguminous plants take up elemental nitrogen for use by bacteria in synthesis of complex nitrogenous compounds.

The chief source of soil nitrogen is organic matter. Only 2–3 per cent nitrogen is in the form of nitrate and ammonia, the rest being present in organic combinations which are very resistant to decomposition. When organic matter decomposes it gives out ammonia. Only readily decomposable organic matter is very resistant to decomposition by soil micro-organisms. A soil may contain as much as 2,250 kg of nitrogen per hectare combined with organic matter, but a mere fraction of this may be available for crop growth.

Some nitrogen is added to the soil through rain-water. It contains ammoniacal and nitrate nitrogen. From 2–22 kg per hectare may be received as combined nitrogen annually through this agency under different environmental conditions.

Most soils contain nitrogen-fixing organisms. The three groups of such organisms are: (*a*) *Clostridia* (*b*) *Azotobacter*, and (*c*) blue-green algae. The bacteria belonging to the group *Clostridia* are of importance in forest soils. They sometimes fix nitrogen in symbiosis with other micro-organisms. *Azotobacter* is met with in all arable lands, except those which are highly acidic or alkaline in nature. Blue-green algae are normally found under wet-soil conditions. They are particularly active in the paddy soils. One or more of those agencies may fix nitrogen from 5 to 17 kg per hectare.

Nitrogen is also fixed in the soil by the leguminous plants, most species of which develop nodules on their roots. The latter are seats of the nitrogen-fixing process. They contain bacteria which live in symbiosis with the plant roots. The plant supplies carbohydrates to the bacteria and the bacteria synthesize elemental nitrogen into proteins. While most of this protein nitrogen is used up in growth and seed development some of it is excreted into the soil from the nodules when they are active or after their decay.

The leguminous plants differ very widely in their power of nitrogen fixation and building up a stock of it in the soil. The nodule bacteria are grouped, according to the leguminous plant in which they are found, as follows:

1. Lucerne or sweet clover (*Medicago* and *Melilotus*)
2. Clovers (*Trifolium*)
3. Pea and vetch (*Pisum, Lathyrus, Vicia, Lens*)
4. Soybean (*Glycine*)
5. Lupin and serradella (*Lupinus, Ornithopus*)
6. *Phaseolus—Phaseolus vulgaris, P. coccinus* and *P. angustifolia*
7. A large, ill-defined group containing most of the crop legumes such as cowpea, groundnut, lespedeza and the rest of *Phaseolus* species.

These legumes differ markedly in their nitrogen-fixing capacity. The bacteria belonging to the group *Glycine* (soybean) fix very little nitrogen in the soil and most of it is removed by the plants for their development. In fact, best yields are obtained when soybean is top-dressed with nitrogen in addition to phosphate. Groups 1, 2, 3 and 6 are very active in this respect.

For beneficial results it is necessary to inoculate the soil with the bacterial culture of the appropriate legume. Forage legumes, such as lucerne, berseem and other clovers, add much more nitrogen than oilseeds and legumes, like soybean, groundnut, cowpeas and peas. The former may add 170–220 kg of nitrogen per hectare annually; a part of this is available only for the succeeding crop. The grain legumes may add from 11–30 kg of nitrogen, but ground soybean actually depletes the soil of nitrogen.

One of the most productive methods of adding nitrogen to the soil is through green manuring. The amount of nitrogen added to the soil varies with the kind of crop, the time allowed for it to grow and the state of its decomposition. Sunnhemp, which is the most popular green manure crop, adds about 75 kg of nitrogen per hectare. On the other hand, a crop of *mung* (*Phaseolus* sp.) may add only 40 kg of nitrogen per hectare.

The nitrogen liberated by a green manure crop can be most effectively utilized when it is available as ammoniacal or nitrate nitrogen after the decomposition of the green matter. Under Indian conditions it takes four to eight weeks for the green-manure crops to decompose and liberate nitrogen for the succeeding crops.

Other sources of nitrogen supply are bulky organic manures which include farmyard manure, farm compost, town compost, oilcakes, fish manure, nightsoil poudrette, sludge and sewage, and nitrogenous fertilizer. Their value as organic manures and fertilizers has been discussed in Chapter IV.

The maximum amount of nitrogen is available from anhydrous ammonia and the minimum from leaf compost. Bone-meal, nitrophos, niciphos II, nitrophoska, monoammonium phosphate and diammonium phosphate are phosphatic fertilizers which have combined nitrogen in their composition. The availability of nitrogen from bulky organic manures is much less than that from concentrated organic manures. The latter take much less time to decompose in the soil than the former. They release their plant food almost as rapidly as the fertilizers do. Of the fertilizers, bone-meal releases nitrogen slowly, particularly in alkaline soils.

Phosphorus: The chief sources of phosphorus in the soil are the minerals, apatites $[Ca\,(OH)_2\ 3Ca_3\,(PO_4)\,]$ and flour apatites. Phosphates are also held on the surface of hydrated iron and possibly aluminium oxides. Besides, organic phosphates, such as phytin and nucleic acid, are also met with in soils, which on decomposition release phosphorus for absorption by crops. Normally the total phosphorus present in the soils is quite high in most of the mineral soils, but only a small part of it is available for the use of crops. A maximum amount is available when the soil is neither acidic nor alkaline in reaction.

Large natural deposits of rock phosphate exist in several countries, namely the U.S.A., Morocco, Algeria, the U.A.R., Norou Islands in the Pacific, the U.S.S.R., India and a few other countries. These are exploited and used as fine powder or as raw material for conversion into superphosphate of various grades or for manufacture into compound fertilizers.

In India high-grade rock phosphate is available in Chota Nagpur in limited amounts. On the other hand, Trichy-nodules, though available in large deposits, are rather uneconomical to collect for processing into superphosphate. Thus, for the manufacture of superphosphate most of the rock phosphate is imported and converted into single superphosphate. A limited quantity of hyperphosphate is also imported into the country for use on acid soils. Basic slag available from the steel plants as a by-product of the industry, contains less than 5 per cent of P_2O_5. The response and economics of its use are still under investigation.

Potash: The chief sources of potash are the potash-bearing minerals found in the soil. These are potash micas, biotite and muscovite. The potash micas weather readily as compared to potash felspar or thoclose. In nature these minerals, by weathering, decompose and release large quantities of potash plant food, except when the soil is extremely acidic (pH below 4). Potash deficiency in the Indian soils is more commonly experienced in acidic soils than in neutral or alkaline soils.

Originally the world source of potassic fertilizer was the Stassfurt mines in Germany. Subsequently, potash deposits were discovered in France, Spain, Poland, Russia, the U.S.A., Canada and Palestine. These minerals are carnallite, kainite and sylvite. The commercial potassium sulphate contains 48–50 per cent of potash (K_2O), and muriate of potash has 60–63 per cent of potash. Wood-ash contains about 4–5 per cent of potash and farmyard manure about 0.6 per cent.

Calcium: Soils derived from basic rocks, such as basalts, give rise to clay minerals which contain calcium. The chief ores are basic plagioclases. These weather readily and yield calcium as plant food for the crop. Besides, calcium carbonate is present in adequate quantities in most of the Indian soils in the form of *kankar* or calcium nodules. The extremely acid soils are partially devoid of calcium because of heavy and constant rains in the regions where they occur.

Wood-ash contains 22 per cent of calcium. The other source of calcium is limestone. The deposits of limestone are met with in all countries of the world. India possesses quite extensive deposits, which so far have not been exploited for use as fertilizers or soil amendment. There is an urgent need to use lime on acid soils in the country.

Magnesium: This occurs in clay minerals, which on weathering readily yield the magnesium into soil solution. This has sufficient quantity of magnesium to meet crop requirements. But the deficiency, wherever it exists, can be met by supplementing it by application of magnesium sulphate or dolomite limestone. Wood-ashes also contain magnesium.

Sulphur: In the soil, sulphur is one of the ingredients of organic matter. It is also met with as elemental sulphur and in the combined form with some of the clay minerals. Generally the amount present in the Indian soils is sufficient to meet the needs of crops.

Deposits of gypsum, which is a good source of agricultural raw material for sulphur, occur in Bikaner. Deposits of flowers of sulphur are met with in the Himalayan Ranges, but these are uneconomic. Ordinary superphosphate, sulphate of ammonia, sulphate of potash and bulky organic manures supply sufficient amounts of sulphur to meet the needs of crops. Gypsum is ordinarily applied to saline-alkali soils to neutralize their alkalinity and restore their productivity.

Minor nutrients

Iron: It is normally available in abundant quantities from the organic matter and soil minerals. Its availability increases on addition of organic matter and sulphur (gypsum) to the soil, particularly when the soil is calcareous or alkaline in nature. Since it is required in small quantities it is sprayed on crops as ferrous sulphate. Sometimes, iron silicate is applied to the soil to meet iron deficiency in trees, particularly in the calcareous soils.

Manganese: The amount of manganese required by plants is small. It is usually available in organic matter and in clay minerals present in the soils. Sometimes excessive quantities of manganese are available and plants show typical symptoms of iron chlorosis. Overliming of soils sometimes shows up manganese deficiency, which is generally offset by the application of manganese sulphate. The deficiency due to overliming is corrected by spraying 1–2 kg per hectare of manganese sulphate.

Boron: The organic matter and minerals are the chief sources of supply of boron. Some of the irrigation waters (boron range, 0.5–2.5 ppm), as in the River Valley of California, contain high amounts of boron. Its accumulation in the soil has proved detrimental to citrus plants. As plants take up more and more of calcium and potassium, they need relatively greater supply of boron. In the arid irrigated areas boron deficiency is sometimes very acute.

The crops normally absorb sufficient quantity of boron for optimum production. Borax is applied to meet boron deficiency in acid sandy soils. Sometimes its application is necessitated when soils show high content of lime.

Zinc: Soil minerals, on weathering, provide the necessary amount of zinc for crop production. This amount, present in the soil, appears to depend upon the parent rocks and the kind of weathering processes. Zinc deficiency is restricted to very heavy soils or very sandy soils formed from silicious rocks, such as gneiss, quartz or sandstone. On such soils micro-organisms sometimes compete with plants for zinc requirements. Some plants, such as lucerne, can extract this nutrient more than other crop plants.

The quantity of micro-nutrient necessary to meet the deficiency in plants in zinc-deficient soils is small. This is commonly met by spraying a solution of zinc sulphate, particularly for the fruit trees.

For a farm crop a liberal supply of farmyard manure meets the requirements of this nutrient.

Copper: Soils which are derived from quartz and sandstone and are of sandy nature manifest copper deficiency. Copper is a part of the soil minerals and is made available through the weathering of rocks. On peaty soils its availability is limited. Its deficiency is normally met with by the application of sulphate to the soil. In the calcareous soils copper is fixed rapidly by soil colloids. Sometimes, crops respond to zinc if copper is also applied simultaneously.

Molybdenum: The minerals on decomposition of rocks provide molybdenum for the nutrient requirements of the crop. On almost all soils the crop requirements are met with, except for the clovers which have high requirements. Clovers fail to fix nitrogen in the absence of adequate supply of molybdenum. In acid sandy soils of Australia, New Zealand and Tasmania its deficiency is very clearly manifested.

FUNCTION OF NUTRIENTS IN CROP GROWTH

In the nutrition of a crop various nutrients perform distinct functions. Their relative essential role depends upon whether they enter into chemical composition or regulate the various physiological processes in the plant.

Carbon. The plant absorbs carbon dioxide directly from the atmosphere. This combines with water in the presence of light and forms the primary sugars, such as glucose and fructose (fruit sugar). Chlorophyll is the pigment which absorbs the radiant energy of the sun and brings about complex chemical synthesis of carbon dioxide and water resulting in simple sugars. This process is technically called photosynthesis or synthesis in light. Thus, by the combination of carbon with water, sun's energy is stored in the plant body, and the first carbohydrates are formed in the plant. From the carbohydrates complex sugars (disaccharides and polysaccharides), starches, hemicelluloses and celluloses (hexosans and pentosans) are formed.

These simple sugars (pentoses—$C_5H_{10}O_5$ and hexoses—$C_6H_{12}O_6$) also polymerise (chemically combine) into oils and fats. For instance, the soluble carbohydrates (sugars) decrease from 37.5 to 4.5 per cent during the ripening of sunflower seed. Same has been observed about oil in *coltai* and niger seeds. This process is indicated as:

	Glycerine	
Carbohydrate	Saturated fatty acids	Unsaturated other acids

The reverse process takes place when seeds germinate. Fats and oils stored in the seed give rise to carbohydrates. This polymerization or conversion (hydrolysis) occurs due to the presence of enzymes, which are organic catalytic agents in the plant.

Oxygen. Oxygen is part of water as well as carbon dioxide. When water combines with carbon dioxide oxygen is evolved:

$$6CO_2 + 6H_2O \text{——} C_6H_{12}O_6 + 6O_2$$

Thus, the oxygen evolved in the process equals the volume of carbon dioxide absorbed by the plants. This evolution of oxygen takes place in the process of photosynthesis.

The process is reverse in respiration when a simple or a complex sugar, fat or oil breaks up. It requires oxygen and gives out CO_2.

$$\underset{\text{(Glucose)}}{C_6H_{12}O_6} + 6O_2 \text{——} 6CO_2 + 6H_2O$$

Six molecules of carbon in the glucose combine with six molecules of oxygen to form six molecules of carbon dioxide. In the process six molecules of water are formed. Thus, oxygen plays a dominant role in the processes of photosynthesis and respiration in plants.

Hydrogen. It is one of the most important elements in the nature. It readily combines with oxygen to form water and with carbon to form complex chemical organic compounds. The growth of plants would only take place if adequate quantity of water is supplied to meet the needs of hydrogen for synthesis of organic substances. When organic compounds either break up in the plant or decompose in the soil or atmosphere, the released hydrogen always combines with oxygen and forms water. Thus, the exchange of hydrogen takes place in either of the synthesis or decomposition (including respiration) processes.

Nitrogen. Carbon is not only an essential part of carbohydrates, fats and oils but also an essential ingredient of proteins. Other constituents of proteins are oxygen, hydrogen and nitrogen, usually sulphur and sometimes phosphorus. The majority of the proteins have the following composition (in per cent):

Carbon	50.0–55.0
Hydrogen	6.5–7.3
Nitrogen	15.0–17.6
Oxygen	19.0–24.0
Sulphur	3.0–5.0

When proteins decompose through hydrolysis they give out amino acids; reversely, when proteins are formed or synthesized the basic substances are amino acids.

Nitrogen is the basic nutrient which forms chlorophyll, amino acids, proteins, alkaloids and protoplasm. In the plant sap ammonia, nitrates and nitrites are found only in traces or very small quantities. When the plant takes up large quantities of nitrogen from the soil the colour of the plant changes to dark-green, indicating the increase of chlorophyll in the plant. Since the amount of chlorophyll in the plant determines the carbohydrate synthesis, nitrogen, in a way, may be said to control this activity. When there is less uptake of nitrogen, the leaves remain small and pale-yellow in colour. As the level of nitrogen supply increases, compared with other nutrients, the extra protein produced enlarges the leaves which provides larger leaf surface for photosynthesis and makes the leaves more succulent and less coarse, increases the length of the growing season and delays maturity. In relation to shoot growth the root growth is depressed. It helps in seed formation and increases the food and feed value of crops. But when the crop plants become more succulent due to larger availability of nitrogen they become susceptible to pests and diseases.

Phosphorus. It is a constituent of the cell nucleus, essential for cell division and the development of meristematic tissues at the growing points. Therefore, plants which cannot absorb adequate quantities of phosphorus from the soil have small root system and leaves, and their growth is stunted. In cereals tillering is reduced and maturity is delayed. Phosphorus is particularly helpful in the production of legumes, as it increases the activity of nodular bacteria which fix nitrogen in the soil. It aids the formation of seeds and fruits, particularly in the legumes. Optimum quantity of phosphorus available to the crop in combination with nitrogen balances their shoot and root growth.

Potassium. Unlike nitrogen and phosphorus, potassium is not a constituent of the carbohydrates, oils, fats and proteins, the substances which form the fabric of the plants. But it plays a vital role in the formation or synthesis of amino acids and proteins from ammonium ions which are absorbed from the soil. It is also considered essential in the photosynthetic activity of the leaves. When potassium is in short supply the carbon dioxide is synthesized into sugars more slowly than when it is available in optimum quantity. The relative concentration of sodium and calcium also influences the activity of potassium in the plant. It helps in moving manufactured food, viz. carbohydrates (sugars) and proteins (amino acids), from leaves to roots. It favours the growth of legumes in competition with other plants. The stalks and stems (of plants) are more stiff when an adequate supply is available than otherwise. In consequence, the lodging in cereals is reduced. It increases the plumpness of the grains. In general it imparts vigour and resistance to diseases. Some crops, such as potato, tomato, clovers, lucerne and beans, are more responsive to potassium than to other crops. As larger quantities of carbohydrates and proteins are stored, it increases winter hardiness of some plants, such as lucerne.

Sulphur. Sulphur is a constituent of many proteins, and aids in the formation of chlorophyll and root growth. Plants having an abundant supply of sulphur develop dark-green leaves and extensive root system. In legumes the nodular activity is appreciably increased by adequate supply of sulphur. Due to larger availability of proteins the plant growth is vigorous.

Calcium. Calcium appears to be essential for the formation of cell-walls, as calcium pectate forms part of the middle layer of the cell-wall. The middle lamella regulates the entry of only those nutrients which are not toxic to the plant. In root-tips calcium is very essential for the meristematic activity or formation of new tissues. It also helps to keep up sustained activity of the nodule bacteria in legumes.

Besides its direct nutrient value, calcium when applied to acid soils increases the availability of other nutrients, like phosphorus, nitrogen and molybdenum. Excess of calcium in the calcareous soils depresses the uptake of potassium and magnesium. These are secondary effects of calcium on plant growth.

Magnesium. The chlorophyll development is much reduced when magnesium uptake is restricted because it is an integral part of the pigment. It maintains the dark-green colour of leaves and regulates the uptake of other materials, particularly nitrogen and phosphorus. It appears to play an important role in the transport of phosphorus, particularly into the seeds. It is also said to promote formation of oils and fats, possibly by increasing photosynthetic activity in the leaves.

Iron. Although iron does not enter into the composition of chlorophyll, its deficiency manifests itself in chlorosis, yellowing or whitening of leaves. The concentration of iron ions plays an important part in the oxidation process in leaf cells. When iron is not taken up in adequate quantity, the growth of plants is less vigorous, and seed and fruit development suffers as a consequence of decreased photosynthetic activity in the leaves.

Manganese. Manganese is an essential element and appears to have a role in the formation or synthesis of chlorophyll. In the absence of deficiency of manganese the carbohydrate synthesis is disturbed, resulting in retarded growth, decrease in the content of ash and failure to reproduce. The leaves and roots of plants deficient in manganese have much less of sugars than those which can absorb sufficient quantity of manganese. Manganese, probably in association with iron, is a constituent of some respiratory enzymes and some enzymes responsible for protein synthesis from the amino acids formed in the leaves.

Boron. One of the most marked effect of boron deficiency observed is the restricted development of nodules on the roots of legumes. Very little nitrogen is fixed in these nodules. Besides, its deficiency influences the growing points of stems, buds and roots. The tissues carrying the minerals and water from the soil to the leaves are also disorganized in the absence of boron. The leaves become brittle. Many deficiency diseases, such as internal cork of apples, heart rot of sugar-beets, top rot of tobacco and cracked stem of celery, are caused by its deficiency.

Zinc. In a general way zinc is associated with the development of chlorophyll in leaves and a high content of zinc is correlated with a high amount of chlorophyll. In its absence growth is less, buds fall off and seed development is limited. In peach and apricots zinc-deficiency symptoms are manifested in leaf. In small trees bronzing of leaves is mitigated by spraying zinc sulphate on leaves. The citrus mottling of leaves may be frequently due to the deficiency of zinc in the plant.

Copper. In the chloroplasts of leaves there is an enzyme which is concerned with the oxidation-reduction processes. The presence of copper appears to be essential for this enzyme to function. Thus, copper plays an important role in the process of photosynthesis. Deciduous fruit trees affected with chlorosis, rosetting and dieback recover quickly on application of copper sulphate to the soil in amounts ranging from 0.22 to 0.90 kg per tree.

Molybdenum. The presence of molybdenum is very essential for the fixation of atmospheric nitrogen in the roots of legumes by nodule bacteria. In plants it is essential for the nitrate-reducing enzyme, as plants well supplied with ammonium do not need it as an essential element. The deformity of 'whiptail' produced in cauliflower is due to the deficiency of molybdenum.

Considering the role played by various essential elements they may be grouped as follows:

Group I	Energy exchangers	Hydrogen and oxygen
Group II	Energy stores	Carbon, nitrogen, phosphorus and sulphur
Group III	Translocation regulators	Potassium, sodium, calcium and magnesium
Group IV	Oxidation-reduction regulators	Iron, manganese, molybdenum, copper, boron and zinc

This grouping is based on the physiological functions of the elements in the synthesis of carbohydrates, proteins, fats, oils, enzymes and other substances which are part of the active mass of protoplasm. In plants all functions are well co-ordinated for growth and development. Growth is disturbed in proportion to the deficiency of any of these nutrients.

Since nitrogen, phosphorus and potassium are required in comparatively much larger quantities, these are called fertilizer elements. Calcium and magnesium requirements are usually met with by the application of lime. These are, therefore, called 'lime elements'. Limestone, which contains these nutrients, is applied to acid soils. The remaining elements, viz. iron, manganese, boron, zinc, copper and molybdenum, required in small quantities are termed minor elements.

NUTRIENT SUPPLY AND CROP GROWTH

A crop can subsist and yield at sub-optimum level while feeding on the lowest stage of nutrition of the element. This is termed as 'minimum percentage'. There is another range of element round this minimum at which the crop can absorb and grow faster in proportion to the increase in supply of the limiting element. This range is termed as 'poverty adjustment'. Within this range there is no excessive uptake of the nutrient. The increase in the supply of the nutrient is accompanied by substantial changes in plant growth and very little of the nutrient is stored in the tissues of the plant till a critical percentage is reached. Above this level very little growth takes place due to some other nutrient limiting the growth of the crop, or due to non-utilization of the nutrient in the growth processes in the plant. Above the critical percentage the uptake of the nutrient is rapid but it is not synthesized into products which contribute to the growth of the plant. This stage is termed luxury consumption of the nutrient. This relationship holds good for most of the nutrients except where toxicity is manifested. Luxury consumption is well known to occur in the case of potassium.

The relationship between the yield of crops and the nutrient supply has been experimentally determined by various workers. Mitscherlich, determining the relationship, observed that a crop should yield a certain maximum yield if all conditions are ideal, but if any essential nutrient is deficient there is a corresponding reduction in the yield. The increase in crop yield by a unit of increment of the limiting nutrient is proportional to the decrement from the maximum. This has been expressed mathematically by Mitscherlich as follows:

$$\frac{dy}{dx} = (A-Y)^c$$

In this equation y is the yield obtained when x is the amount of nutrient present, A is the maximum yield obtainable if the nutrient was present in excess and c is the constant. Where $x=0$ and $y=0$, the curve assumes the following form:

$$Y = A(1-e^{-cx}).$$

The factor c in these equations is a constant for each fertilizer, independent of the crop, soil or other conditions. Thus, given the value of c and the results of a fertilizer trial the experimenter can predict the yields with increasing levels of that fertilizer.

Interaction of nutrients. Often a nutrient in deficient supply restricts the growth due to non-availability of it to the plant. In turn other nutrients though available in optimum quantity are unable to show their effect to the maximum extent possible. Alternatively, when the nutrient in limited supply is made up in the soil, the other nutrients which were showing limited response previously show up their full response. This effect is known as 'interaction of nutrients'. Technically speaking, the law of minimum operates in the responses of two essential nutrients required for optimum growth. If only one is added it will have little effect on growth, while application of both of them will have appreciable effect and the response to two together will have larger than the responses to individual nutrients. Under such circumstances the interaction is said to be positive. However, when the response to two nutrients together is less than the sum of the responses to each factor separately the interaction is termed negative. The interaction is positive when both the nutrients are in the minimum; it is negative when one of them is in excess and is being absorbed in larger quantity than is required in the optimum, and proves toxic in the growth processes. The experimental evidence to indicate the positive and negative interactions, obtained in field experiments, will be reported in Chapter XI.

The interaction of nutrients is particularly of importance in relation to potassium, magnesium, calcium, sodium and minor elements. A minimum balanced concentration of these is essential for regulating the growth processes in the plant, particularly the functions of translocation of nutrients from the soil to the growing points of the shoots and the roots, and the oxidation-reduction functions concerned with respiration, photosynthesis, polymerization, hydrolysis, digestion and other processes. The relative concentrations of these nutrients depend upon their relative availability in the soil. When any of them is present in excess it is absorbed in larger quantity than the other nutrients, and relatively the concentration of the other nutrients is reduced with consequent appearance of deficiency symptom of the nutrient in short supply, resulting in deficiency disease or restricted growth of the crop. For example, large dressings of lime after hoeings bring about magnesium and potassium deficiencies if the soil has low content of these two nutrients. This has serious repercussions on growth and subsequent yield of crops, which is less than anticipated. In other words negative interaction comes into evidence. In the art of manuring for top yields the farmer is very much concerned with optimum supplies of all nutrients to the crop so that negative interaction of nutrients (or hidden hunger) never comes into play, rather the positive interaction is manifested at all stages of growth of the crops.

DEFICIENCY SYMPTOMS

The plants exhibit hunger signs when they cannot adequately absorb plant nutrients. These symptoms of hunger for nutrients are readily recognizable under field conditions. The hunger can be

readily satisfied by the application of fertilizers to the soil. The symptoms of malnutrition are described below.

Nitrogen. The nitrogen-deficient plants are light-green in colour. The lower leaves turn yellow and in some crops they quickly start drying up as if suffering from shortage of water. The growth is stunted and stems or shoots are dwarfed. In cereals tillering is restricted. In corn if nitrogen deficiency persists the yellowing will follow up the leaf midrib in the typical V-shaped pattern with the leaf margins remaining green. The drying up of lower leaves is generally referred to as firing. In small grains, namely, wheat, barely and oats, the nitrogen-starved plants are erect and spindly and the leaves have yellowish-green to yellow colour. The stems are purplish-green. In potato, in the later stages of growth, the margins of lower leaflets lose their green colour and become pale-yellow. In cotton the blades and petioles are reduced in size, turn yellow or brown and die. Plants produce fewer lateral branches, reduced number of fruiting branches, and very much reduced number of flowers and bolls. In legumes the growth is stunted and the lower leaves are pale-yellow or brownish in colour. In citrus the leaf shedding is heavy. Their leaves are small in size, thin and fragile and have light-green colour. In deciduous fruit trees the leaves have yellowish-green appearance. The old, mature leaves are discoloured from base to tip. Under prolonged deficiency, twigs become hard and slender. In vegetables there is retarded growth with leaf chlorosis. The stems are slender, fibrous and hard.

Phosphorus. Generally the plant is dark-green but the lower leaves may turn yellow and dry up. Growth is stunted and leaves become smaller in size. In corn, leaves and stems have a tendency to become purplish; young plants are stunted and dark-green in colour. Small grains have dark-green colour and often have purplish tinge. They have retarded growth. In potato, in early stages, the plants have stunted, spindly growth. The tubers have rusty-brown lesions in the flesh in the form of isolated flecks which some times join together to produce larger discoloured areas. The cotton plants have dark-green colour, leaves and stems are small, and the bolls mature late. Besides the dark-green colour of legume plants, their petioles and leaflets are tilted upwards. The plants are spindly and stunted. Their stems often turn red. In citrus the plants show reduced growth. The older leaves at first lose their deep-green colour and lusture, and develop faded green to bronze colour.

Necrotic areas develop on such leaves. In deciduous fruit trees the young leaves have dark-green colour while mature ones have bronze or ochre dark-green colour. The new twigs are slender. In vegetables although the growth is retarded the leaves do not show symptoms of chlorosis. In many crops the under surface of leaves develops reddish-purple colour. The stems are slender and woody. They bear small, dark-green leaves.

Potassium. The margins of leaves turn brownish and dry up. The stem remains slender. In tobacco there appear small spots of dead tissue between the veins, at leaf tips and margins which are tucked or cupped up. In maize, in the young stage, the edges and tips become dry and appear scorched or fired. At a later stage in well-grown plants the leaves are streaked with yellow and yellowish-green colour, and the margins dry up and get scorched. Similar symptoms are shown by oats, wheat and barley. In potato the deficiency of potassium is acutely manifested. The plant growth is retarded, the internodes are somewhat shortened, the leaf size is reduced and they form a sharper angle with the leaf petiole. The leaflets become crinkled and curve downward. The older leaves become yellowish, develop a brown or bronze colour, starting from the tip and edge and gradually affecting the entire leaf, and finally die. Malnutrition symptom in cotton is observed in 'cotton rot', which first appears as yellowish-white mottling and then changes to yellowish-green; subsequently yellowish spots appear between the veins. The centres of these spots die and numerous brown specks occur at the top, around the margin and between the veins. The breakdown first occurs at the tip and margin of the leaf. The leaf curls downwards before it becomes reddish-brown and dries up. In legumes the first symptoms consist of yellow mottling around the edges of the leaf. This area soon dries up and dies. The plants have stunted growth. In citrus there occurs excessive shedding of leaves at blossom time. There is a tendency for the young shoots to shed before they become hardened. The leaves are small. In deciduous trees the necrosis (death of tissues) in foliage occurs, the necrotic areas varying in size from very small dots to patches or extensive marginal areas. Foliage, especially of peach, becomes usually crinkled. Twigs are usually slender. In vegetable crops in the older leaves bronze and yellowish-brown colours are manifested near the margins. Specks develop along the veins of the leaf. Ultimately the tissue deteriorates and dies.

Magnesium. The symptoms of magnesium deficiency at first manifest themselves in old leaves. In tobacco the lower leaves are chlorotic but do not show dead spots. The tips and margins of the leaf are turned or cupped upwards. The stalks are slender. In maize leaves a slight yellow streak develops between the parallel veins in the leaves. In acute deficiency these streaked tissues may dry up and die. In small grains the plants are dwarfed and turn yellow. Sometimes leaves exhibit yellowish-green patches. In potato the affected leaves are brittle. The chlorosis in legumes begins at the tip and margins of the lowermost leaf, and progresses between the veins towards the centre of the leaflet. Eventually the tissue between the veins is filled with brown, dead areas. In cotton the lower leaves have purplish-red colour with green veins. In legumes the areas between main veins of the leaves become pale-green, which later turn deep yellow. At a later stage of growth the leaf margins curl downwards accompanied by a gradual yellowing and bronzing from the margin inward. In vegetable crops the symptoms are similar. The chlorosis appears first between leaf veins of new leaves and then spreads to older leaves. The chlorotic areas become brown or transparent and ultimately marked necrosis of affected tissue occurs. In citrus trees the green colour fades in the leaf, parallel to the midrib, and spreads from there. However, the base of leaf usually remains green even in very advanced stages of deficiency of magnesium in the plants. In deciduous fruit trees necrosis occurs as fawn-coloured patches on most mature, large leaves. The affected leaves drop, leaving a tuff or rosette of thin, dark-green leaves at the terminal part of the twigs.

Calcium. Generally the deficiency symptoms due to calcium starvation are localized in new leaves and in bud leaves of plants. In severe cases the terminal bud dies. In tobacco the young leaves making up the terminal bud first become typically hooked and dieback at tips and margins. The stalk finally dies back. In maize the tips of the unfolding leaves gelatinize and when they dry they stick together. In potato a light-green band appears along the margins of the young leaves of the bud. The leaves often have a wrinkled appearance. In cotton calcium deficiency makes the petioles bend and later collapse. In vegetables the stems grow thick and woody, and the new leaves are chlorotic. The new growth lacks turgidity. In legumes the nodules developed are small and fewer in number. In cirtus the green colour fades along the edges of the leaf and this spreads to areas between veins. The symptoms appear first in immature leaves of deciduous fruit trees, especially those at the top which dieback from tips and margins or along the midribs. Later on the twigs also dieback.

Zinc. Various plant species show different symptoms of zinc deficiency. In tobacco lower leaves are at first involved. They are mottled or chlorotic with spots which rapidly enlarge involving secondary and primary veins in succession. The leaves are thick. They have short internodes. On maize seedlings, 'white bud' disease is noticed. It is a type of chlorosis or fading of dark-green colour. These are small white spots of inactive or dead tissue. The leaves of opening buds have white or light yellow colour. Hence the zinc deficiency disease is called 'white bud' disease. Potato plants without zinc form greyish-brown to bronze-coloured irregular spots, usually appearing in the middle of the leaves. The affected tissue sinks and finally dies. Extreme deficiency of zinc manifests in chlorotic conditions and in darker-coloured veins of leaves. It is difficult to distinguish these symptoms under field conditions. In vegetable crops the new leaves have mottled appearance with yellow colour. In acute cases the necrotic or dead areas are found on new leaves.

Boron. The deficiency symptoms of this nutrient are usually localized on nerve or bud leaves of the plant. In tobacco the young leaves have light green colour at their bases. This is followed by break-down of these tissues. In old leaves with acute deficiency they show twisted growth. The stalks finally dieback at the terminal bud. In corn the younger leaves are dwarfed. Their tissues are white and the growing tips dead. Under field conditions the plants have weaker ear-shanks and stalks. Their leaves are yellowish in colour. In the potato fields boron-deficiency symptoms occur in the tubers rather than on the veins. The tubers on boiling show much sloughing, are fairly saggy and have a flat flavour. In sand culture devoid of boron the plants are short and bushy. The growing points are soon killed and the growth of lateral buds is stimulated. The leaves thicken and margins roll upwards. The leaf points and margins of older leaves die prematurely. The tubers, besides being small in size, have a ruptured surface. In cotton the effect is localized to terminal buds which dieback, resulting in multi-branched plant. The young leaves are yellowish-green and flower buds are chlorotic. In vegetables the growing tissues of stems and roots are involved. The new bud leaves and petioles have light colour, are brittle and are often deformed in shape. Rosetting due to short internodes is pronounced at the shoot terminals. The legumes also have rosetting at the terminal buds. The buds appear as white or light brown dead tissue. The plants have little flowering. In citrus the deficiency symptoms are localized to new growth. New leaves have water-soaked flecks, which become translucent. The fruits have hard, gummy lumps in the rind. In deciduous trees symptoms appear on terminal tissues of twigs. The young leaves have chlorotic appearance and are wrinkled. Due to severe deficiency the twigs and spurs show symptoms of dieback.

Manganese. In this case also the symptoms are localized to terminal buds which remain alive, but the bud leaves are chlorotic with veins light or dark-green. In tobacco the young chlorotic leaves develop dead tissues scattered over the leaf. The smallest veins tend to remain green, which gives chequered effect on the leaves. In oats the 'grey speck' disease has been found associated with manganese deficiency. In potato the terminal buds remain alive, chlorosis of newer tissue occurs and numerous small brown patches develop which in time become more extensive. In cotton the terminal buds remain alive but upper or bud leaves become yellowish-grey or reddish-grey while veins remain green. In vegetables the new leaves become chlorotic while veins remain green. In cereals the leaves turn brown or transparent; this is followed by necrosis of the affected tissues. In legumes the terminal buds remain alive but leaves become light green or yellow with green veins. Later on, dead tissues appear on the leaf. Although in citrus the leaves have normal shape and size their veins remain green while the tissue in between becomes light green to grey in colour.

Iron. The iron-starved plants have short and slender stalk. Their terminal buds remain alive but their new leaves show chlorosis of tissues in between the veins, which themselves remain green. In tobacco the young leaves from the terminal buds show chlorotic appearance. The veins of these leaves remain typically green. In young leaves a slight uniform chlorosis is at first noticed. The margins and veins retain green colour. The leaves gradually become pale-yellow and subsequently white. In vegetable crops the new leaves develop light yellow colour in between the veins. Later on the entire leaf becomes yellow. In legumes the leaves turn yellow with the veins remaining green, and on leaves spots of dead tissues appear, particularly at the margins. These dead tissues, in due course, drop away. In citrus the dying of twigs is common, accompanied by chlorosis of leaf tissues in between the veins. The growth of plants is very much restricted.

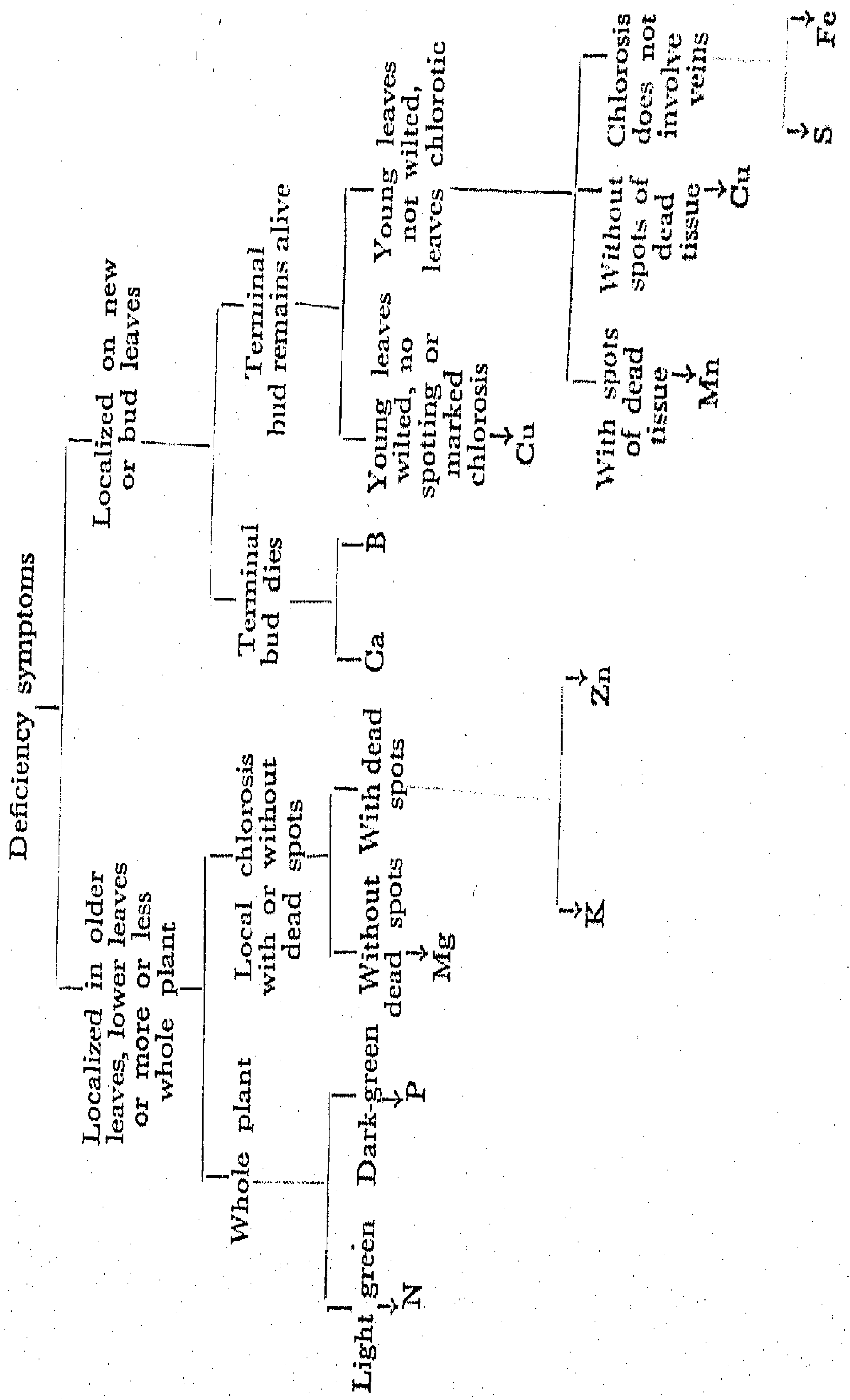
Copper. The terminal buds remain alive but wilting or chlorosis of bud leaves takes place with or without spots of dead tissues.

The veins of these leaves remain light or dark-green. In tobacco the young leaves remain permanently wilted. They donot have spotting or marked chlorosis. Deficiency in potato is recognized by the wilting of young leaves and loss of turgor of terminal buds which drop when flower buds are developing. There is no pronounced chlorosis but drying of leaf tips occurs in advanced stages. In vegetables the growth is retarded and leaves lack turgidity. They exhibit chlorosis as if they are bleached. In legumes the young leaves wilt with or without chlorosis. In extreme deficiency there may occur excessive leaf shedding. In citrus the large leaves are frequently malformed, and have a fine network of green veins on a light green background. The fruits have gummy excrescences.

Sulphur. Generally the terminal bud remains alive. The chlorosis of younger leaves takes place. In tobacco the whole leaf has light green colour; only younger leaves show these symptoms without injury to terminal buds. The symptoms of chlorosis in young leaves of potato develop slowly but growth of plants is materially checked. Similar dwarfing of plants occurs in cotton but the green colour of new leaves does not show any change. In vegetables, the leaves develop yellowish-green colour, and become thick and firm. The stems harden and sometimes become abnormally elongated and spindly. In legumes the younger leaves turn pale-green to yellow, while terminal buds remain alive. The growth of citrus slows down. The new leaves develop very light yellow-green to yellow colour.

Molybdenum. The deficiency is markedly evident in legumes, particularly in the subterranean clover. Molybdenum-starved plants have yellowish to pale-green colour.

A schematic chart is given on the next page to indicate the broad distinguishing features of these deficiencies.


Deficiency symptoms
Localized on new or bud leaves
Terminal bud remains alive
Young leaves wilted, no spotting or marked chlorosis → Cu
Young leaves not wilted, leaves chlorotic
With spots of dead tissue → Mn
Without spots of dead tissue → Cu
Chlorosis does not involve veins
→ S
→ Fe
Terminal bud dies
Ca
B
Localized in older leaves, lower leaves or more or less whole plant
Local chlorosis with or without dead spots
Without dead spots → Mg
With dead spots
→ K
→ Zn
Whole plant
Light green → N
Dark-green → P

CHAPTER II

SOILS AND CLIMATE

INDIA, probably, presents a greater variety of meteorological conditions, actions and features than any other area of similar size in the world. Its climate is varying (Table 1): the north has very different conditions from the south, the coasts from the interior and the West Coast from the East Coast. The normal annual rainfall varies from about 1,100 cm in Assam Hills and 700–1,000 cm at suitably exposed positions on the crests of the Western Ghats to less than 7 cm in Rajasthan. At one period of the year parts of India are deluged with rain and at another persistent dry weather prevails for weeks or months. Coasts are occasionally affected by cyclones. These bring up storm waves that sweep over the low-coast lands of lower Bengal or the deltas of the Mahanadi, Godavari and Krishna rivers.

India presents a noteworthy combination of tropical and temperate conditions. Tropical heat, heavy and frequent rain and fierce cyclones are prevalent at one period of the year, while moderate temperature and rain with shallow, extensive storms at another period.

SOILS

The soils of India may broadly be classified as follows:

1. Red and yellow
2. Red loam
3. Red gravelly
4. Laterite
5. Laterite (old alluvium)
6. Deep black or *regur*
7. Medium black of trap and gneissic origin
8. Shallow black
9. Black (undifferentiated)
10. Mixed red and black
11. Alluvial
12. Coastal alluvium
13. Grey and brown of the Indus, the Yamuna and the Gangetic basins impregnated with varying amounts of salts
14. Gangetic alluvium (calcareous)
15. Saline and alkali
16. Desert (grey)
17. Desert (brown)
18. Skeletal
19. Forest and hill (undifferentiated)
20. Brown under deciduous forests
21. Mountain meadow
22. Podsolised
23. Glaciers and eternal snow
24. Submontane regional including *bhabar* and *terai*.
25. Peat.

TABLE 1. ZONES OF THE CLIMATE OF INDIA

Zone	Regions comprising the Zone	Annual rainfall (in centimetres) and their periods	Temperature	Humidity (per cent)	Seasons of the year
A	Assam except the belt along the northern banks of Brahmaputra river	More than 250, throughout the year	26.7°–31.1°C	87–94	Cold and rainy seasons; no summer
B	Bihar, West Bengal, Orissa, major parts of Madhya Pradesh, parts of north-east Tamil Nadu and eastern Uttar Pradesh	120–220; June to Sept., Dec. to Jan. and May; in West Bengal March to October	1.7°–47.8°C	60–85	Alternate dry and wet seasons
C	Most of eastern and southern Tamil Nadu	50–100; mostly through north-east monsoon	Hot temp. in low rainfall	High rainfall parts are humid throughout the year	Wet and dry seasons
D	Kerala and parts of Tamil Nadu	250–370; during nine months	21.7°–35.6°C	Damp almost throughout the year	Dry only in three months
E	Western Maharashtra, i.e., Kanara, Ratnagiri, Kolaba (Thana Dist. and southern Gujarat)	Over 250; June to October		High humidity	Wet and dry seasons

TABLE 1.—(*Contd*)

Zone	Regions comprising the Zone	Annual rainfall (in centimetres) and their periods	Temperature	Humidity (per cent)	Seasons of the year
F	Central Gujarat, Khandesh, parts of Madhya Pradesh, east of Maharashtra, Mysore and central Tamil Nadu	50–120; June to Oct. mostly, less than one-third in Oct. to Nov.	1.1°–47.8°C	Low humidity	Rainy, winter and summer seasons
G	Eastern Rajasthan, western U.P., Punjab and Himachal Pradesh	50–120	Very high in summer and very low in winter	..	Winter and summer seasons
H	Western Rajasthan and northern Gujarat	50	..	..	Mostly dry
I	Jammu and Kashmir, and northern Himachal Pradesh	Rains almost throughout the year	..	..	Severe winter season with snowing

The soil groups which have been extensively studied are: (i) the red soils, (ii) the laterite soils, (iii) the black soils, and (iv) the alluvial soils.

Red soils. The red soils of India, including red loams and yellow earths, occupy about 518,000 km^2 and extend over a large part of Madras, Mysore, south-east Maharashtra and a tract along the estern part of Madhya Pradesh to Chota Nagpur and Orissa. In the north and north-east these extend into and include great part of the Santhal Parganas of Bihar; Birbhum, Bankura and Midnapur districts of West Bengal; Khasi, Jaintia, Garo and Naga Hills areas of Assam, Nagaland and Meghalaya; Mirzapur, Jhansi, Banda and Hamirpur districts of Uttar Pradesh; Baghelkhand division of Madhya Pradesh and the Aravallis and the eastern half of Rajasthan.

The main features of these soils, besides their lighter texture and porous and friable nature, are: (*a*) the absence of lime *kankar* and free carbonates, and (*b*) the usual presence of soluble salts in a small quantity, not exceeding 0.05 per cent. These soils are generally neutral to acid in reaction, and deficient in nitrogen, phosphoric acid, humus and perhaps lime. They differ greatly in depth and fertility, and produce a large variety of crops under rainfed or irrigated conditions. They are divided into two broad classes: (i) the red loams, characterized by a cloddy structure and the presence of only a few concretionary materials; and (ii) the red earth with loose top-soil, friable but rich secondary concretions of a sesquioxidic clayey character.

The soil contains a high percentage of decomposable hornblende, suggesting a comparatively immature nature. The silica-alumina ratio of the clay fractions is 2.7–2.46 and their base exchange capacities are below 20 m.e. per 100 g, suggesting their predominantly kaolinitic nature.

In the typical red earth the silica-alumina ratio of the clay fractions is higher than 2 and they are fairly rich in iron oxide.

The soils have undergone excessive weathering and very low amount of decomposable mineral hornblende.

In Tamil Nadu the red soils occupy nearly two-thirds of the cultivated area. They are rather shallow, open in texture with the pH ranging between 6.6 and 8.0. They have a low base status and low exchange capacity, and are deficient in organic matter, poor in plant nutrients, and with the clay fraction ratio of 2.5–3.0.

The predominant soil in the eastern tract of Mysore is the red soil, overlying the granite from which it is derived. The loamy red soils are predominant in the plantation districts of Shimoga, Hassan and Kadur. They are rich in total and available K_2O, and contain fair amounts of total P_2O_5 (0.5–0.3 per cent); the lime content is 0.1–0.8 per cent, nitrogen below 0.1 per cent, and iron and alumina 30–40 per cent.

A broad strip of area lying between the eastern and western parts of Coorg is red loam, easily drained and with a fairly dense growth of trees.

The acid soils in the south of Bihar (Ranchi, Hazaribagh, Santhal Parganas, Manbhum and Singhbhum) are red soils. Their pH is 5.0–6.8 and they have high percentage of acid-soluble Fe_2O_3 as compared with Al_2O_3; sufficient available potash but P_2O_5 is low. The soils from Manbhum, Palamau and Singhbhum are preponderant in zircon, hornblende and rutile respectively; those of Ranchi contain a mixture of epidote and hornblende, neither of which is preponderating.

In West Bengal the red soils, sometimes misrepresented as laterites, are the transported soils from the hills of the Chota Nagpur Plateau.

The existing tracts of soils in north-west Orissa are quite heterogeneous. There seems to be a prominent influence of the rolling and undulating topography on soil characteristics.

The soils are slightly acidic to neutral in reaction and the total soluble salts are fairly low. Ferruginous concretions are invariably met with, whereas calcareous concretions are present only in a few cases at lower depths of the profiles.

In a typical red soil profile the total exchangeable bases is about 20 m.e., the SiO_2-R_2O_3 ratio of the clay fractions varies between 2 and 3, and the C-N ratio is near about 10.

The soils of Raipur district (Chattisgarh area) are grouped into the following classes:

Matasi: Upland or level land soils, yellow, loam to clay loam and loamy clay yielding good paddy.

Dorsa: Soils along the slopes, somewhat darker; same texture as above; good paddy lands.

Kanhar: Lowland soils, dark, slightly heavier than the above; paddy the main crop; wheat also grown.

Bhate: Barren waste lands with gravel and sandy reddish-yellow; usually in uplands.

A part of Jhansi district (Uttar Pradesh) comprises red soils. These are of two types: *Parwa*, a brownish-grey soils varying from good loam and sandy or clayey loam, and *rakar*, the true red soil generally not useful for cultivation.

In the Telengana Division of Andhra Pradesh both red and black soils predominate. The red soils or *chalkas* are sandy loam located at higher levels and are utilized for cultivation of *kharif* crops.

Another type of soil occurring in Andhra Pradesh is locally known as *dubba*. It is loamy sand or very coarse sandy loam, and mostly pale-brown to brown with reddish-brown patches here and there; clay content quite low (less than 10 per cent) and very low fertility; invariably neutral in reaction and low in soluble salt content. The content of organic matter is little to negligible. The soils are severely eroded with surface soil depth below 12.7 cm and very often covered with multisized gravels and cobbles. Being sub-marginal lands they are well suited for pasture and forage crops rather than for rice growing.

Laterite and lateritic soils. These soils occupy an area of about 126,000 km^2 in India. The laterite is specially well-developed on the summits of the Deccan Hills, Central India, Madhya Pradesh, the Rajmahal Hills, the Eastern Ghats, in certain plains of Orissa, Maharashtra, Malabar and Assam. This is found to develop under fair amount of rainfall, and alternating wet and dry periods. The laterite and lateritic soils are characterized by a compact to vasicular mass in the subsoil horizons composed essentially of mixture of the hydrated oxides of aluminium and iron. These soils are deficient in potash, phosphoric acid and lime. On higher levels these soils are exceedingly thin and gravelly, but on lower levels and in the valleys they range from heavy loam to clays and produce good crops, particularly rice.

Both the high-level and low-level laterites occur in Tamil Nadu. They are both *in situ* and sedimentary formations, and are found all along the West Coast and also in some parts of the East Coast, where the rainfall is heavy and humid climate prevails.

In the laterites on lower elevations paddy is grown, while tea, cinchona, rubber and coffee are grown on those situated on high elevations. The soils are rich in nutrients and contain 10–20 per cent of organic matter. The pH is generally low particularly of the soils under tea (pH 3.5–4.0) and at higher elevation.

In Maharashtra laterites are found only in Ratnagiri and Kanara; those in the latter are coarse, poor in lime and P_2O_5, but fairly good in nitrogen and potash. In the former coarse material abounds in large quantities. These are rich in plant food constituents, except lime.

In Kerala, between the broad sea-belt consisting of sandy soil and sandy loams and the eastern regions comprising the forest and plantation soils, the mainland contains residual laterite. This is poor in total and available P_2O_5, K_2O and CaO. Laterite rock in Cochin is found to the east of the alluvial areas in Trichur, Talapalli and Mukundapuram *taluks*. Soil is mostly laterite in Trichur *taluk*. The nitrogen varies from 0.03–0.33 per cent; the lime is very poor and the magnesium is 0.11–0.45 per cent. The laterite soils in Mysore occur in the western parts of Shimoga, Hassan, Kadur and Mysore districts. All the soils are comparable to the laterites and to the similar formations found in Malabar, Nilgiris, etc. These soils are very low in bases, like lime, due to severe leaching and erosion. These are poor in P_2O_5. The pH is not as low as that in the plantation soils.

In West Bengal the area between the Damodar and the Bhagirathi is interspersed with some basaltic and granitic hills with laterite capping. Bankura district is known to be located in the laterite soils zone. The SiO_2–Al_2O_3 ratio of the clay fraction is quite high. The percentage of K_2O, P_2O_5 and N are also low, showing considerable leaching and washing out of these substances due to chemical weathering. The soils of Burdwan are in all respects similar to the Birbhum and Bankura soils with one or two exceptions. The high value of the SiO_2–Al_2O_3 ratio is significant.

In Bihar laterite occurs principally as a cap on the higher plateau but is also found in some valleys in fair thickness.

The laterites of Orissa are found largely capping the hills and plateau occasionally in considerable thickness. Large areas in Khurda are occupied by laterites. At Balasore it is gravelly and appears to be detrital. Raychaudhuri and co-workers recognized two types of laterites in Orissa, the laterite *murrum* and the laterite rock. They may occur together.

Black cotton soils. These soils cover a large area throughout the southern half of the peninsula, the Deccan Plateau, greater part of Maharashtra State, western parts of Madhya Pradesh and Andhra Pradesh, and some parts of Tamil Nadu, including the districts of Ramnad and Tinnevelly. The black soils or *regur* include a large number of physiographic regions, each within a zone having its own combination of soils. These soils may be divided into three groups: (i) deep and heavy; (ii) medium and light; and (iii) those in the valleys of rivers flowing through *regur* area.

The main features of the black soils are: (i) depth one to two to several m deep; (ii) loamy to clayey in texture; (iii) cracking heavily in summer, the cracks reaching up to more than 3 to 4 m in depth, especially in the case of heavy clays; and (iv) containing lime *kankar* and free carbonates (mostly $CaCO_3$) mixed with the soil at some depths. These soils are often rich in montmorilllonitic and beidlite, group of minerals, and are usually suitable for the cotton cultivation. They are generally defilient in nitrogen, phosphoric acid and organic matter; potash and lime are usually sufficient. The content of water-soluble salts is high, but the investigations carried out in connection with Tungabhadra and Nizamsagar projects have shown that these soils may be irrigated without any danger, if irrigation is carried out on sound lines.

Though the black soil has no distinct demarcation of horizons between the unweathered parent material and the weathered soil, the soil profile may be said to possess approximately three principal horizons A, B and C; the alluvial or A horizon being predominant and of two types, namely, darker with high organic matter content and lighter. The zone of accumulation of carbonates ($CaCO_3$) and sulphates (chiefly $CaSO_4$) may be taken as the B or alluvial horizon. In regions of fairly high and evenly distributed rainfall the zone of carbonate accumulation is found deeper in the profile and sometimes incorporated with horizon C.

The occurrence of black and red soils in close proximity is quite common in India. In Bombay soils derived from the Deccan trap occupy quite a large area. On the uplands and on the slopes the black soils are light coloured, thin and poor; and on the lowlands and the valleys they are deep and relatively clayey. Along the Ghats the soils are very coarse and gravelly. In the valleys of the Tapti, the Narmada, the Godavari and the Krishna heavy black soil is often 6 m deep. The subsoil contains good deal of lime. Outside the deccan trap the black cotton soils predominate in Surat and Broach districts. Degraded solonized black soils, locally known as *chopan*, occur along the canal zones in the Bombay Deccan.

A number of black soil profiles have been examined in Tamil Nadu. They are either deep or shallow and may or may not contain gypsum in their profile, and accordingly four types of profiles are distinguished: (i) shallow with gypsum, (ii) shallow without gypsum, (iii) deep with gypsum, and (iv) deep without gypsum. The shallow profiles are 3 to 4 m deep, often with partially weathered rock material even at a depth of 0.5–1.0 m; the deep ones extend even up to 3.0 m or more.

The black soils are very heavy, contain 65–80 per cent of finer fractions, have high pH (8.5–9.0) and are rich in lime (5-7 per cent); they have low permeability, high values of hygroscopic coefficient, pore-space, maximum water-holding capacity and true specific gravity. They are low in nitrogen but contain sufficient potash and P_2O_5. They have generally a high base status and high base exchange capacity (40–60 meg); about 10–13 per cent iron content, and the CaO and MgO contents are formed from a variety of rocks, including traps, granites and gneisses.

In Madhya Pradesh the black soils are either deep and heavy (covering the Narmada Valley) or shallow (in the districts of Nimar, Wardha, west of Nagpur, Saugar and Jabalpur). The cotton-growing areas are mainly covered by the deep heavy black soils which, however, gradually change in colour from deep-black to light. The $CaCO_3$ content increases with the depth. Clay content is 35-50 per cent, the organic matter is low and SiO_2–R_2O_3 ratio is 3–3.5.

The black soils of Mysore are farly heavy with high salt concentration, and rich in lime and magnesia. The SiO_2=R_2O_3 ratio of clay fraction is 3.6.

Alluvial soils. The so-called alluvial soils of India form an ill-defined group. Various types of alluvium are classed as alluvial, e.g., calcareous soils, saline and alkali soils, and coastal soils.

The alluvial soils occur mainly in the southern, north-western and north-eastern parts of India: the Punjab, Uttar Pradesh, Bihar, West Bengal, parts of Assam, Orissa, and coastal regions of southern India including the local deltaic alluvia. These soils are the most fertile amongst the Indian soils. The whole of the Indo-Gangetic plain is, in this alluvial area of 777,000 km². These soils are very deep, deeper than 90 m at some places, and deficient in nitrogen and humus, occasionally in phosphoric acid but not generally in potash and lime. They produce a variety of crops, including rice, wheat and sugarcane. They may be sub-divided into two broad groups, the old and the new; both are geological groupings. The former, locally called *bangar*, represents reddish-brown, sandy loams with increasing content of clay in the lower horizons; the latter, known as *khadar*, represents the fairly coarse sand on the *chars* and banks of the river to the soils of very fine texture in the low-lying marshy tracts. The old alluvium, reddish in colour, is deficient in nitrogen and humus, and occasionally in phosphoric acid.

The large expanse of these soils is yellowish to brownish and their common feature is the presence of *kankar* or lime nodules intermixed with soil at varying depths. They vary from sandy loam to clayey loam. The subsoil occasionally has calcareous reaction. There is no marked differentiation into the various horizons, and the profile is often characterized by the absence of stratification. The surface soil is generally grey, varying from yellow to light brown, the intensity of colour increasing with the depth.

The immature soil near the rivers is calcareous and light brown in colour with salt impregnation. On higher situations it becomes brown to deep brown in colour and is non-calcareous. Kankar beds are found in the soil. Most of the alluvial soils in Uttar Pradesh and Bihar are of the above pattern.

Forest and hill soils. Nearly 14 per cent of the total area of India is under forests. The formation of forest soils is mainly governed by the characteristic deposition of organic matter derived from the forest growth. Broadly two types of soil-formation may be recognized: (i) soils formed under acid conditions with presence of acid humus and low base status; and (ii) soils formed under slightly acid or neutral condition with high base status which is favourable for the formation of brown earths.

The soils of the hilly districts of Assam are of fine texture and reveal high content of organic matter and nitrogen, perhaps due to the virgin nature. Their chemical and mechanical composition show great variations.

In Uttar Pradesh the sub-Himalayan tract comprises three regions, viz. *bhabur* area immediately below the hills, *terai* and the plains. Four major groups, i.e., red loams, brown forest soils, podsols and transitional podsols, and *wiesenboden* have been observed in the Himalayan tract; of these, brown forest soils and podsols are predominant. The *terai* area is characterized by excessive soil moisture and luxuriant vegetation. The soils are clay loam, loam and sandy loam. The loam may have high content or minor quantities of lime, or lack it altogether.

In the Punjab the typical soil profiles under deodar, spruce, blue pine and *chir* are related to the podsols but have significant differences, probably due to the relatively high calcium content of the first layer. These differences are brought out in the high degree of saturation of various horizons.

The weathering of metamorphic rocks in Coorg has produced very fertile deep surface soil which annually receives the decomposition products of the virgin forest. The areas towards the west are for the greater part reserved forests and mountain areas. The land surface has a laterite bed, is easily drained and is full of pebbles.

In Nilambur the soils which do not grow teak are more clayey, contain more MnO and possess a lower SiO_2-R_2O_3 ratio; this makes it suitable for teak plantation.

The cinchona-growing soils of West Bengal resemble brown earths. Their surface layer consists of well-decomposed humus and mineral soil which shades off gradually, at varying depths, into the colour of the parent rock. This soil is strongly acidic in reaction. Their high base exchange capacity is due to the high organic matter content. Water-soluble manganese is present in appreciable amount.

Desert soils. A large part of the arid region belonging to Rajasthan and the south Punjab, lying between the Indus and the Aravallis, is affected by desert conditions of recent geological origin. This part is covered under a mantle of blown sand which inhibits the growth of soils.

The Rajasthan desert proper (area about 103,600 km²), owing to its physiographic conditions receives no rain though lying in the tract of the south-west monsoon. Some of the desert soils contain high percentage of soluble salts, high pH, low loss on ignition, varying percentage of calcium carbonate and poor organic matter, the limiting factor being mainly water. The soils could be reclaimed if proper facilities for irrigation are available.

Saline and alkaline soils. The distribution of saline and alkaline soils is extensive throughout India in all climatic zones. Many parts of the north especially Bihar, Uttar Pradesh, the Punjab and Rajasthan, give rise to saline and alkaline efflorescence in the same way as the soils capping the Upper Tertiary rocks. There are many yet undecomposed mineral fragments in these alluvial clays and silts, which, on weathering, liberate sodium, magnesium and calcium salts. Large areas, once fertile and populous, have become impregnated with these salts locally known as *reh* or *kallar* with highly deleterious effects on their fitness for cultivation. The injurious salts are confined to the top layers of the soils, which are charged by capillary transference of saline solutions from the lower layers. This transference is facilitated in lands irrigated by canal waters.

Reh is a mixture of carbonate, sulphate and chloride of sodium, and some other salts of calcium and magnesium. It is also introduced by rivers and canals. The water of the great alluvial plains which are without any underground drainage become concentrated with salts. Capillary action during the summer months brings them to the surface where they form a white efflorescent crust.

It has been estimated that 80,960 hectares of land in the Punjab have been affected by *usar* and 10,120 hectares are being added every year. Methods of reclamation based on irrigation, application of lime or gypsum, where necessary, and growth of salt-resistant crops like rice, berseem and sugarcane have been suggested. In cases of badly damaged alkali patches, treatment with sulphur or gypsum accompanied by adequate watering has led to steady improvement in the soil, and successful crops have been raised.

The soils of Hardoi, Lucknow and Kanpur districts are characterized by very high pH values and by almost complete absence of gypsum due to restricted internal drainage Soils appear to be the carbonate chloride type of saline-alkali in contrast to soils of more arid localities of temperate climates.

The alkaline soils of Unnao district are of three types: (*a*) immature salty alkaline; (*b*) salty alkaline, without a zone of $CaCO_3$ accumulation and with a zone of $CaCO_3$ accumulation, and (*c*) degraded salty alkali. This alkalinity is due to downward leaching of salty solution arising primarily from soil decomposition.

Alkali soils are met with all over the states of Gujarat and Maharashtra, but badly affected lands are found in Gujarat, Karnatak and the Deccan.

Such soils show high content of exchangeable monovalent bases and magnesium with a predominance of chlorides, amounting to more than 50 per cent. Reclamation of these lands by bunding and leaching of soluble salts is possible.

Portions of Dharwar district and Bijapur *taluk* are affected by what is locally known as *kari* soils, which are saline-alkaline, fairly deep and clayey. The salt lands of the Nira Valley have developed as a result of excessive irrigation given to the deep black soils of the locality. In these soils two groups of profiles, one resembling steppee alkali soils and the other the solonetz, might be distinguished.

The soils of Delhi State have one of these pedogenic groups: (*a*) saline (mostly in the *khadar* area); and (*b*) saline-alkali, with *kankar* formation (mostly in *dabar* and *bangar* areas, and in depression of *khadar* areas).

Peaty and marshy soils. Peaty soils originate in humid regions as a result of accumulation of large amounts of organic matter in the soil. They may also contain considerable amounts of soluble salts. They are found in Kerala. They are generally submerged under water during the monsoon. After the rains these are put under paddy cultivation. Soils are black, heavy and highly acidic, with pH as low as 3.9, and contain 10–40 per cent of organic matter. Their acidity is due to the decomposition of organic matter under anaerobic conditions, and no nitrification is possible. Sometimes the soils contain ferrous and aluminium sulphates.

The depressions formed by dried river-basins and lakes in alluvial and coastal areas sometimes give rise to peculiar waterlogged and anaerobic conditions of the soils. The soils of these places are generally blue due to the presence of ferrous iron and contain varying amounts of organic matter. Marshy soils of this type are found in the coastal tracts of Orissa, the Sunderbans and some places in Bengal, central portion of north Bihar, Almora district of Uttar Pradesh, and south-east coast of Tamil Nadu.

CHAPTER III

GREEN MANURE

GREEN manuring is the practice of enriching soil by turning under soil undecomposed plant material, mostly of leguminous plant (except crop residues). This was practised in India from ancient times. But the systematic use and popularization of green manuring was done by European planters in tea or coffee plantations. This preceded the first experiments tried under Government auspices. The low status of organic matter and nitrogen in Indian soils as compared with European soils, was a striking feature met with by researchers trained in England. Green manuring was one of the methods of improving the soil fertility to which the Agricultural Departments turned their attention. Experiments on green manuring were conducted as early as in 1893 at Kanpur, Nagpur and Dumraon.

With the expansion of Agricultural Departments and establishment of the Imperial Agricultural Research Institute at Pusa (Bihar) in 1905, work on green manuring was taken up by many specialists. The consensus at that time could be recapitulated by quoting Howard in 1912, a pioneer of this field in India: "The importance of increasing the water-holding capacity and fertility of the soil is so great in India and green manuring is such an easy way of bringing this about that no pains should be spared to find out experimentally the factors on which success depends.

In addition to the field experiments it is also desirable that the matter should be investigated from the chemical and biological aspects". This well-founded optimism of Howard was natural because the factors that governed the level of organic carbon in soil were not very well known to the western world. The past 60 years of research on the dynamics and mechanics of organic-matter maintenance all over the world has, however, shown that green manuring may not always increase the soil organic matter. The research work on this practice started with the promise that it would increase the fertility of soil and its water-holding capacity. Emphasis was, therefore, placed on working out the techniques to make it a success in different notations. The crops used for green manuring, green-leaf manuring, techniques of green-manuring and the response of crops to this practice are summarized in this chapter. This is followed by a discussion on the relative contribution of above-ground and under-ground parts of green-manure crops in increasing the yield of subsequent crops and the effect of green manure on soil properties and its place in modern Indian agriculture.

GREEN MANURE CROPS

Some common green manure crops are described briefly in the following pages.

Sunnhemp, *Crotalaria juncea*: It is the most common green manure crop in India. It is used as a green manure in practically all the states of the Indian Union the exception being areas prone to waterlogging. It is sown with the break of the monsoon. It grows very fast and attains a height of 1–2 metres. It grows well even on poor soils. The plant contains a large proportion of herbage and does not become woody soon; hence, it is rapidly decomposible on being ploughed in. About 20,000 to 25,000 kg of green matter can be obtained from a hectare in a duration of eight weeks. In addition to being a valuable green-manure crop it furnishes fibre of fair strength.

Wild sunnhemp, *Crotalaria mucronata* (Syn. *C. striata*), is a useful green-manure crop for coconut gardens. It grows wild in waste and uncultivated lands in almost all the major coconut tracts in India. It is hardy and herbaceous, and grows to the height of 1.5 metres or more under favourable conditions. It thrives in a variety of soils, including slightly saline ones when well established it can withstand extremes of rainfall and drought. It bushes out well under coconut shades. It is not relished by cattle and even goats. It is promising at Cuttack (Orissa). In Mysore and Ceylon this plant has been used as a mulch in tea, coffee and rubber estates.

Crotalaria anagyroides is an introduction from Ceylon. The plant is a branching shrub, attaining a height of 2.3 metres. In Bombay it was tried as a cover plant and as green manure in coconut estates.

Dhaincha, Sesbania bispinosa (Syn. *S. aculeata*): As a green manure crop, *dhaincha* is known to stand waterlogging and saline conditions very well. It can also tolerate drought if the germination has been good. It is an ideal green manure crop for rice-growing soils. In waterlogged fields it grows to a height of 1.5–1.8 m in a very short time. The resistance of the crop to waterlogging could be appreciated by the fact that the *dhaincha* crop, both at Etawah and Achalda in Uttar Pradesh, survived even after being submerged to a depth of about 0.6 m for a week. This crop also grows on alkaline soils and is thus used in their reclamation.

Sesbania speciosa: In recent years *Sesbania speciosa* has been popularized as green manure crop in Tamil Nadu, where it was introduced in 1935-36. It can be grown in the paddy fields along with the bunds and incorporated in the soil four to five months after harvest. This plant is not only drought-resistant but can also withstand prolonged submergence. It has a slow growth in the early stages and after a month it grows faster if moisture is available in the soil. At Sambalpur (Orissa), it was found to be more succulent and to withstand drought conditions better than *Sesbania aculeata*. But its rate of growth was slower. A perennial shrub, *Sesbania sesban* (Syn. *S. aegyptiaca*) is also used for green-leaf manuring.

Mung, Phaseolus aureus (Syn. *P. mungo*): This is an annual herbaceous plant cultivated mainly for edible seeds. *Mung* 'Type-1' is a short-duration crop maturing within 60–70 days. If sown with the break of the monsoon, i.e., by the first week of July, it matures by the first week of September enabling two pickings of the ripe pods and yields on a modest average 3–4 q of seed per hectare. The entire crop, after picking the pods, is succulent enough to be turned under as a green manure for wheat. Unlike other green manure crops it does not require the use of heavy soil-turning plough. An average farmer with small bullocks can easily turn it in.

Pillipesara, Phaseolus trilobus: This is comparatively a new green-manure crop, but is now widely used in Tamil Nadu and Andhra Pradesh. It is also a minor pulse crop and its seed is edible. Because of the creeping and spreading habit, *Pillipesara* affords a good cover and thereby prevents weeds from coming up. It grows fast and can be easily ploughed in. It also decomposes quickly. It can be grown either in a standing rice crop in autumn or winter, or after ploughing the soil in summer. *Pillipesara* leaves are relished by cattle, and hence can be grown as fodder-cum-green manure crop.

Among the other *kharif* pulses belonging to the genus *Phaseolus*, *moth* (*P. aconitifolius*) and *urid* (*P. mungo*) are used as green manure to a limited extent.

Wild indigo, *Tephrosia purpurea*: It is a hardy and drought-resistant green manure crop. Its use is now confined to south India. Because of the extremely slow growth it is an ideal green manure for single-crop rice areas, where the land remains fallow for nearly six months in a year. It is always sown in the standing rice crop, just before the water is let off the field for the last time. The crop is ploughed in when it has formed some seeds which remain dormant in the soil. Once a good crop is established, it is not necessary to sow the seeds again, as the self-sown seeds would give a satisfactory crop. It can also be sown mixed with pulse crops following rice so that after the pulse crops are harvested the plants are available for green-manuring.

Guar, Cyamopsis tetragonoloba: *Guar* is used as a green manure crop in the dry and low-rainfall areas of north-western India. This plant grows even on poor soils and makes very good fodder. Cowpea, another fodder crop which grows on all soils, is highly promising as a green manure crop. This crop can either be grown during *kharif* or after the harvest of wheat during summer. Other leguminous plants such as *kulthi* (*Dolichos biflorus*) and lupins are used to a certain extent as green manures.

GREEN-LEAF MANURING

Many types of leguminous and non-leguminous plants are grown on bunds or wastelands for the purpose of utilizing their foliage as green manure.

Gliricida maculata: This plant comes up well on most types of soils. Under certain climates it grows to a height of about 4.5 m. During a year two cuttings can be taken, first at the beginning of the monsoon and the second in December. The observations made in Andhra Pradesh show that it contains (on fresh basis) 8.5 per cent carbon and 0.49 per cent nitrogen. The yield of leafy material per plant according to the observations taken at Cuttack was 22.5 kg after the tenth year.

Pongamia glabra (Syn. *P. pinnata*): The average yield of green matter per tree is about 130 kg. It contains (on fresh basis) 81.5 per cent moisture, 7.2 per cent carbon and 0.57 per cent nitrogen.

Calotropis gigantea: This plant grows wild on fallow lands and road-sides in different soils and climatic regions of the country. The leaves are quite succulent and the weight of green matter per plant is about 5 kg.

Tephrosia purpurea: It is a freely branching and spreading annual shrub found growing in fallow lands. It grows well on well-drained loamy soils. The average yield of green matter per plant is about 0.7 kg in Andhra Pradesh.

Tephrosia candida: This is an erect shrub, resistant to pruning, and is used extensively for green manuring and as a hedge. It is a shady plant and grows largely in tea gardens. The average yield of leafy matter per plant is 2.5 kg from the loppings in the second year.

Indigofera teysmanni: This plant is preferred to *Gliricidia* in Mysore and some other areas.

Cassia tora: The calculated yield reported from Andhra Pradesh was 4,000 kg per hectare. Studies at Kanpur showed that *C. fistula* gives still higher yield of green leaves and twigs for use in paddy fields.

Sesbania speciosa: The practice of growing this plant around the borders of the rice fields, when the crop is standing, was investigated for three years at Cuttack. On an average it produces about 3,450 kg of green matter per hectare within four months for incorporation into the soil for the use of the second crop of paddy in January.

Ipomoea carnea (Syn. *I. crassicaulis*): This is another important plant which can be grown under varied soil and climatic conditions for green manuring. In the heavy-rainfall areas its loppings can directly be used for green-leaf manuring, whereas in the dry areas it can be composted before use.

TECHNIQUES OF GREEN-MANURING

Green manuring will yield rich dividends only when the cultural practices involved in the process are clearly understood. Sowing of the green-manure crop will have to be so arranged as to bury it at a time when it furnishes its nutrients to the subsequent crop at the time the latter needs it. This would also help to check the loss of nutrients.

Soil and climate. Green-manure crops can be grown on any type of soil, provided there is sufficient rainfall or alternatively irrigation available. Poor sandy soils, in particular, benefit most by this practice. The heavy soils are also opened up with the incorporation of the organic matter. Where annual precipitation is less than 65 cm and arrangement for cheap irrigation is not available, green manuring sometimes becomes hazardous.

Sowing time. It is hard to recommend a particular sowing time for a vast country like India, where climate differs from region to region. However, the crop should be sown soon after the break of the monsoon. In northern India sowing may be undertaken from early June in Bihar, middle of June or later in Uttar Pradesh, and July in the Punjab and Rajasthan. The best time for green-manuring in the case of sunnhemp, *urid* and *dhaincha* in Maharashtra is June or early July. The advantage of establishing the crop earlier than the onset of the monsoon is to resist damage from the heavy subsequent rains.

Turning-in of the crop. In a short monsoon season the material must be turned-in by the first week of August. *Dhaincha* crop is ready for turning-in when five-to six-week-old. Chawan and Patil in 1952 recommended 50–60 days for turning-in the entire crop of sunnhemp. In 1914, Hutchinson and Milligan found that four-to six-week-old plants are better than ten-week-old ones. In Mysore the flowering stage is the best time for turning-in the green manure crop. Sethi *et al.*, in 1938 reported that the 57-day-old crop of sunnhemp was the best in nitrogen accumulation.

Decomposition of green manure. A host of micro-organisms affect the complete disintegration of organic matter, leading up to ammonification and, finally, nitrate production. The factors for complete decomposition are the varying moisture conditions of the soil. The desired results would follow if moisture contents are high in the beginning, leading to semi-anaerobic fermentation of resistant material, and low afterwards for inducing aerobic condition, under which nitrification can take place. Thus cessation of the monsoon during early stages of decay largely accounts for loss of manurial effect on the succeeding crops. On the contrary, late and heavy rains tend to destroy the nitrates already formed. Decomposition depends, among other factors, on moisture contents of the soil, composition of green matter and presence of available inorganic nutrients.

The depth to which the green matter is ploughed in and especially its proper incorporation into the soils is also important for quick decomposition. As a rule, in light soils the crops should be buried deeper than that in the heavy ones.

The burying technique under dry-land conditions differs from that of wet-land. In the former, the green manure crop is plouged in with a soil-inverting plough after felling the crop. The ploughing is done in the same direction as felling. Under wet-land condi-

TABLE 2. RESPONSE OF WHEAT TO APPLICATION OF GREEN MANURE (5,600 KG|HA GREEN MATTER) IN DIFFERENT STATES OF INDIA

Sta	Irrigated wheat			Unirrigated wheat		
	Number of Centres	Number of Experiments	Response (kg|ha)	Number of Centres	Number of Experiments	Response (kg|ha)
Uttar Pradesh	5	39	176	—	—	—
Punjab	3	19	132	—	—	—
Madhya Pradesh	3	31	127	3	31	58
Bihar	7	43	122	—	—	—
Delhi	1	14	168	—	—	—
Maharashtra	4	40	135	2	15	137
Gujarat	3	4	228	—	—	—
Total and overall average	26	190	155	5	46	98

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tions ploughing done with trampler, like the Burmess Setan, will be more beneficial. The same will hold good in green-leaf manuring. The technique of green-manuring for paddy grown under wetland conditions differs from that of wheat, as the decomposition is much quicker and easy in paddy than that in wheat.

Most of the experimental results favour growing green manure crop *in situ* for the purpose of turning-in. The advantage of growing the crop outside is to extend the practice on a larger scale without losing the crop season.

The time lag between burying the green crop and sowing of the subsequent crop plays a very important part in the decomposition of organic matter and in making nitrates, formed during the process, available to the following crop. Majority opinion favours a two-month interval for sunnhemp green-manuring.

RESPONSE OF CROPS TO GREEN-MANURING

Wheat. In 1965, Panse *et al.*, summarized the experiments conducted in India on the response of wheat to green-manuring under irrigated and unirrigated conditions from different wheat-growing States of India. As the amount of green matter turned in the soil in these experiments varied they standardized the response to the application of 5,600 kg|ha green matter using appropriate response curves. This compilation offers an opportunity to compare the responses from different States under irrigated and unirrigated conditions (Table 2).

TABLE 3. RESPONSE OF RICE TO GREEN-MANURING AT THE RATE OF 5,604 KG|HA

State	Number of Research Stations	Number of Experiments	Control Yield (kg|ha)	Standardized Response (kg|ha)
Andhra Pradesh	9	86	1,298	285
Assam	3	15	1,191	197
Bihar	10	65	1,266	104
Kerala	1	61	1,290	258
Madhya Pradesh	5	60	1,026	186
Maharashtra	4	17	1,195	257
Mysore	4	32	1,203	253
Orissa	3	57	1,193	225
Tamil Nadu	7	146	1,281	304
Uttar Pradesh	3	23	1,087	249
West Bengal	6	21	1,126	273
Total and overall average	55	583	1,204	236

The data presented in Table 2 show that while under irrigated conditions the response to green-manuring was remunerative it was not so under unirrigated conditions.

Rice. Response of paddy to green-manuring is summarized in Table 3.

On an average there is a response of 236 kg|ha. Except for Bihar, other responses did not show any appreciable difference from State to State. However, in Andhra Pradesh and Tamil Nadu responses were somewhat bigger. One of the probable reasons for the low response in Bihar is that rice there is grown under rainfed conditions and the rainfall is not adequate to provide sufficient quantity of green manure or for its subsequent decomposition.

Sugarcane. Data from 43 experiments conducted in Uttar Pradesh and the Punjab to study the response of sugarcane to green manure were available. The results are shown in Table 4.

TABLE 4. RESPONSE OF SUGARCANE TO GREEN MANURE AT THE RATE OF 5,604 KG|HA

State	Number of Research Stations	Number of Experiments	Control Yield (tonnes|ha)	Response to Green Manure (tonnes|ha)
Punjab	1	5	37.66	9.62
Uttar Pradesh	7	38	48.76	6.10
Total and overall average	8	43	43.21	7.86

The method of application of green manure to sugarcane was *in situ* in all the cases. The most commonly used green manure was sunnhemp. Green manures like *dhaincha, guar, lobia,* pea (*Pisum sativum*, Syn. *P. arvense*), *methi* (*Trigonella foenum-graecum*), *Senji* (*Melilotus indica*, Syn. *M. parviflora*) were also used. The average response of sugarcane to green manuring at the rate of 5,604 kg per hectare was 7.9 tonnes per hectare.

Only in Uttar Pradesh, there were adequate number of experiments. In both the States, there were good responses to green manuring.

TABLE 5. RESPONSE OF COTTON TO GREEN MANURE AT THE RATE OF 5,604 KG|HA

State	Number of Research Stations	Number of Experiments	Control Yield (kg|ha)	Response to Green Manure in (kg|ha *kapas*)
(a) Irrigated cotton				
Gujarat	1	3	424	12
Maharashtra	1	1	2,641	—15
Mysore	2	6	481	114
Tamil Nadu	1	1	361	522
Overall average and total	5	11	977	158
(b) Unirrigated cotton				
Gujarat	2	17	428	40
Madhya Pradesh	1	5	582	84
Maharashtra	8	39	823	(—) 63
Overall average and total	11	61	611	20

Cotton. Results of 61 experiments on unirrigated cotton and 11 on irrigated cotton were available. The data are presented in Table 5.

In almost all the experiments on unirrigated cotton, the sunnhemp and *urid* were grown along with it and incorporated *in situ* one month after sowing of cotton. On an average, there was a depression in yield in Maharashtra. The response in Madhya Pradesh and Gujarat was small and the average response is relatively low.

Very few experiments on irrigated cotton were conducted at Coimbatore in Tamil Nadu, Siruguppa and Mandya in Mysore, Halwad in Gujarat, and Poona in Maharashtra. *sunnhemp* and *dhaincha* were the green manures used in most of the experiments. The variation in response from State to State is quite large. In Tamil Nadu the results are based on single experiment. There was a moderate response of 114 kg|ha in Mysore, whereas in Maharashtra and Gujarat there was no response.

On the whole, green manuring of cotton does not give any appreciable response. On the contrary there is a risk of depression in yield. This is owing to the green-manure crop competing for

TABLE 6. RESPONSE OF POTATO TO GREEN MANURE AT THE RATE OF 5,604 KG|HA

State	Number of Research Stations	Number of Experiments	Control Yield (kg|ha)	Response to Green Manure (kg|ha)
(a) Irrigated potato				
West Bengal	2	2	9,087	(—) 1,307
(b) Unirrigated potato				
Bihar	1	4	16,334	(—) 1,457
Tamil Nadu	1	12	11,404	402
West Bengal	3	3	11,893	(—) 3,224
Overall average and total*	5	19	13,210	(—) 455

* For unirrigated potato.

moisture and soil nutrients with cotton during its growth and decomposition.

Potato. Results of 19 experiments on unirrigated potato and 2 on irrigated potato were available. In most of the experiments green manure was grown *in situ* and applied.

For unirrigated potato the limited data available show large variation in response; there was insignificant response in Bihar, whereas the yield decreased in West Bengal.

RESIDUAL AND CUMULATIVE RESPONSE TO GREEN MANURE

Some experiments on paddy, wheat and sugarcane give indication of the residual response to green manuring. They have been discussed by Panse *et al.*, in 1965. By and large, these responses are poor and mostly last only for a year. The Pusa Permanent Manurial Trial started in 1908 provides an opportunity to study the cumulative effect of the green manuring on the yield of crop. In 1967, Singh has presented data on the total yield obtained during (1908–1962) and the yield trends during (1930–1962) for all rotational crops. The data very clearly indicate that there was no cumulative effect of green-manuring in sub-tropical climate. Similar results have been obtained from other tropical countries. The effect of green manuring on soils discussed in the latter part of this chapter also leads us to a similar conclusion.

COMPONENTS OF GREEN MANURING

Singh in 1967 indicated a basis for apportioning the gains from green-manuring over the yield of the same crop after fallow to two effects designated here as 'legume effect' and 'green matter effect'. Data on the yield of sugarcane, wheat and other crops grown after the following treatments were collected from the results of the experiments carried out in different parts of India:

(i) Monsoon fallow;

(ii) Green manuring with sunnhemp (*Crotolaria juncea*) for sugarcane and with guar (*Cyamopsis tetragonoloba*), *dhaincha* (*Sesbania bispinosa*) or sunnhemp for wheat for assessing the overall effect of green-manuring.

(iii) Green-manure crop grown, but all the above-ground parts removed for assessing legume effect; and

(iv) Plots kept fallow in the monsoon and green material from treatment No. (iii) ploughed in for assessing green matter effect.

These data show that the 'legume effect' and the 'green matter effect' each are responsible for about half the overall benefit from green-manuring.

Data on paddy also gave similar indications. These data show that introduction of other legumes for fodder in place of green manure and application of inorganic nitrogen to the main crop will be more remunerative in sugarcane and wheat rotation.

ADDITION OF NITROGEN THROUGH GREEN MANURE

The bacteria living in the root nodules of plants use the energy from their host plant. With this energy they take in nitrogen from the air and build up complex compounds. Some of these compounds are passed on to the host plant, but a good part of them is left in the root tissues of the ploughed nodules. These compounds later appear in the form of mineral compounds of nitrogen, say, ammoniacal compounds and nitrates, due to the action of other bacteria in the soil.

The amount of nitrogen fixation depends upon the nature of the soil and the legume in a sandy soil, a well-inoculated legume will fix most of its nitrogen in soils with high organic matter, the legumes may obtain as much as half of their nitrogen from the soil.

On a given soil type the amount of legume growth and the nitrogen fixed depend upon how well the soil is supplied with phosphorus, potassium and other nutrients.

As a rule, legumes contain 2.5 to 3 per cent nitrogen on oven dry basis. The roots of annual legumes may contain from 5 to 20 per cent of the nitrogen found in entire plant.

TABLE 7. AMOUNT OF NITROGEN CONTAINED IN SELECTED CROPS IN GOOD GROWTH

Crop	N content (kg/ha)
Senji	80
Guar	60
Lobia	55
Dhaincha	75
Moong	40
Pillipesara	55

EFFECT OF GREEN MANURE ON SOILS

Not much work has been done on this aspect of green-manuring in India. Therefore, data from other tropical countries has also been considered to elucidate the effect of this practice on soils.

Soil structure. There is a certain amount of vagueness on the effect of green-manuring on soil structure. There is no convincing evidence that organics have improved soil structure in India. To form structural aggregates, the individual units of soil separate, e.g., sand, silt and clay, have to be bound and then stabilized. The clay separate is the principal binding agent, and organic matter in association with divalent (primarily calcium) and trivalent cations is the principal stabilizing agent. No one has as yet shown that organic matter itself can play the part of a binding agent in soil structure formation. Martin in 1946, working in Uganda, reported no improvement in soil structure by green manures with or without lime and that under tropical conditions the organic matter is "oxidized or otherwise disposed of before it can be decomposed to colloidal dimensions".

Materials that are resistant to decomposition will have little, if any, effect upon the size distribution of aggregates, but will be effective over a longer period by mechanically loosening the soil. Browning and Milam in 1944 reported that in sandy soils, where the amount of silt and clay in proportion to the sand is often very small to produce other than a single-grained structure, the application of organic material will have little effect on aggregation of the soil. The observations that green manuring has improved the structure of the sandy soils in Kapurthala and sandy soils of Brucepur, Layallpur, are not exactly structural improvements. Sand grains bound by some ever-present glue-like substances in decomposition of organic matter have perhaps been responsible for the apparent improvement of structure, but these have not brought about soil aggregation. This becomes very clear from the data of Pusa Permanent Manurial Trial, started in 1908 on alluvial calcareous sandy loam soils under unirrigated conditions. Data on bulk density, water-holding capacity, moisture equivalent, permeability of surface soils collected from control, phosphated green manure and purely inorganically fertilized plots (NPK) are given in Table 8.

TABLE 8. SOME PHYSICAL PROPERTIES OF SOIL (EXPRESSED ON OVEN DRY BASIS)*

Treatments	Bulk density g/cc	Water-holding capacity (%)	Moisture equivalent (%)	Permeability (cc/hr)
O	1.72	34.3	19.1	0.82
NPK	1.74	35.2	22.0	0.75
Green manure +P	1.68	36.7	20.0	0.85

*Biswas *et al.*, 1962

Thus after more than 50 years of green-manuring there is no appreciable change in the bulk density of the soil and water-holding capacity. Hygroscopic moisture percentage, which is an indication of the capillarity of the soil, has also not increased.

Soil moisture. Organic colloids have a very high water-retention capacity and can markedly increase the field capacity of mineral soils. The organic matter added in green manures does not have colloidal dimensions. As a matter of fact, in warmer climates it burns out so rapidly that the soil is enriched only in salts left behind. Not many critical experiments have been conducted in this country to assess the effect of green manures on the field moisture capacity or infiltration capacity of soils.

TABLE 9. CUMULATIVE EFFECT OF GREEN-MANURING ON MOISTURE RELATION OF SOILS

Treatments	Water retention			Moisture Hygroscopic (%)
	1/10 atm (%)	3 atm (%)	15 atm (%)	
O	23.8	18.1	2.4	0.83
NPK	24.1	19.8	3.9	1.40
Green manure +P	24.4	17.6	3.1	1.02

Lander *et al.*, in 1923 studied the effect of green-manuring with a legume and a non-legume on sandy and stiff soils and reported that the addition of green manures to sandy soils increased the water-holding capacity by about 3 per cent over the control. The difference in the case of stiff soils was, however, not significant. This experiment does not cover a sufficient period. Thus, from his data it would be difficult to conclude that water-holding capacity of the soil is increased by green-manuring. The data of permanent manurial plots are given in Table 9 to illustrate the cumulative effect of green manuring on the water relation of soil.

The hygroscopic moisture, an indirect measure of the capillary pore space, is high in soils receiving purely inorganic fertilizers. Similarly, available water as calculated from the difference between the moisture content at 1/3 atm tension and 15 atm tension is lower in plots receiving phosphated green manure than purely inorganic fertilizers. Thus, even the long-term application of green manure did not affect any appreciable change in the moisture relation of the soil.

In 1950, Plice analysed the soils of the green-manured (for 16 years continuously) and non-green-manured plots of a prairie soil of Oklahoma. He found that green-manured soil had a lower field-moisture capacity and rate of water infiltration. These are in agreement with the finding of Pusa Permanent Manurial Trials.

Organic matter. As stated by Russel in 1950, green-manuring has, in most parts of the world, been applied more successfully to increasing the available nitrogen supply than the humus content of soils. As a matter of fact green manuring can either increase the humus content or the supply of available nitrogen in the soil, but it can rarely replenish both at the same time. Therein it differs from the effect of well-decomposed farmyard manure. The humus content increases appreciably if material fairly resistant to decomposition is added to the soil, and decomposition-resistant plant material which is typically low in nitrogen. The available nitrogen supply is only increased if readily decomposible material, high in nitrogen content such as young plants, decomposes in the soil.

In humid tropics and sub-tropics mineralization rather than humification dominates the decomposition reactions of organic materials incorporated into soils. Singh in 1967 has shown on the basis of the data of the Pusa Permanent Manurial Trial started in 1908 that green-manuring has not resulted in any great change in the organic matter content of the soil.

TABLE 10. ORGANIC CARBON CONTENT OF SOILS OF SELECTED PLOTS OF PUSA PERMANENT MANURIAL TRIAL

Treatment	Organic carbon content of soils (%)			
	1940-41	1947-48	1954-55	1957-58
Control	0.223	0.212	0.229	0.280
NPK	0.235	0.292	0.245	0.365
Green manure	0.228	0.291	0.257	0.358
Green manure + P	0.300	0.315	0.261	0.430

These data reveal that the organic carbon content of the control plots has remained virtually constant, having reached an equilibrium value commensurate with the cultivation practices and systems of cropping and soil management. This value is probably the asymptotic value under the present management. Purely green manure plots have maintained a slightly higher organic carbon content but the organic carbon content plots receiving inorganic fertilizers has been maintained at a yet higher level. The green manure plots with phosphate have considerably maintained the highest organic carbon content.

Long-term experiments of Ware and Johnson in 1951 have shown that it is "difficult to maintain and even more difficult to increase the organic matter" in the soils of Alabama by green-manuring. Similar results have been reported in 1926 by Mooers in Tennesses, in 1947 by Thompson and Smith, in 1953 by Thompson and Robertson in Florida, and in 1953 by Bonnet and Luga Lopez in Puerto Rica.

There is another facet of this problem. The freshly decomposing organic matter when added to the soil accelerates the decomposition of the native organic matter. This was observed by Lohnis in 1926 long before the radio-tracer technique was applied to verify this statement experimentally. In 1947, Broadbent and Norman using isotopic N^{15} and C^{13} in freshly added organic matter (Sudan grass) conclusively demonstrated that green manure under the conditions of the experiment actually speeded decomposition of the original soil organic matter. They speak about the freshly added green matter as a forced draft on the smouldering bacterial fire. More carbon and nitrogen were liberated from the original soil organic matter in the presence of green manure than when the soil was left untreated with the green manure and summer-fallowed under these conditions. Broadbent in 1948 concluded that the addition of fresh organic matter can bring about a net decrease in the soil organic matter especially if small amounts of readily decomposible matter are added frequently to the soil. This was also confirmed by Hallam in 1953 who found that small amounts of fresh organic matter destroyed more humus than they added through the synthesis of new stable humus. A critical study of this problem by Bingeman *et al.*, in 1953 fundamentally confirmed the findings of this school but quantitatively found 'Priming' effect of the fresh additives in their experiments to be scarecely significant and not always reproducible. Further experiments are needed on these lines to confirm these conclusions.

Plant nutrients. In 1955, Joffe remarked that the primary importance of the nutrient supply effect of the green-manuring practice gains very strong support from investigations on burning the crop instead of incorporating it by ploughing or discing. Faulkner and Mackie in 1933, Freize in 1939, Mehta in 1950, Vine in 1953, and Singh in 1963 have showed that burning was just as effective and in some cases even superior on the succeeding crop as the conventional methods of handling green manure crops. Vine's data cover a period of 20 years of observations in Nigeria. On the basis of these findings it is logical to conclude, as stated by Scherbatoff in 1949, that in Nigeria "the efficiency of green manure crop in accumulating readily available minerals as well as the nitrogen is the primary function of green manuring".

Green-manure crops utilize the nutrients which without them would be leached. They also mobilize other nutrients.

Nitrogen. There are at least three ways in which green manures after decomposition lead to better nitrogen nutrition of subsequent crops. Leguminous green manures fix nitrogen from the air; they utilize the nitrate from the soil, which, but for them, could have been leached, and after nitrification these two forms

become available. The third avenue of better nitrogen nutrition of subsequent crop is not well appreciated yet. By adding easily decomposible organic matter the rate of decomposition of native organic matter is increased and the release of soil nitrogen occurs (These results have been verified in 1947 by Broadbent and Norman in laboratory experiments and in 1947 by Chapman and Liebig in the field).

Other elements. Decomposing organic matter has a solubilizing effect on phosphorus, potassium and trace elements. There are several mechanisms through which phosphorus becomes readily available. The increased solubility of phosphorus might be owing to: (*a*) production of large quantity of carbon dioxide during decomposition of organic matter, leading to a lowering of the pH of the soil solution; (*b*) conversion of mineral phosphate under the influence of decomposing organic material to organic phosphate which becomes available to the subsequent crop; and (*c*) precipitation of iron and aluminium by certain organic anions, thus liberating phosphate from the basic phosphates of these elements at very low pH values. These anions are formed from acids like citric, oxalic, tartaric and lactic, which are produced in considerable quantity as a result of microbial action on plant residues and which are nature's effective agents for complexing iron and aluminium in acid soils and releasing phosphates for plant use.

Decomposing plant materials are also likely to increase the availability of trace elements which are immobilized at a high pH. It appears, therefore, that the decomposition of readily decomposible organic matter releases its contained nutrients as well as nutrients from soil. These stimulate crop growth. The benefits of green-manuring are obtained when conditions are established for the complete decomposition of the green matter. The addition of green leaf from outside has the same effect. The dictum that green manure is of no value unless decomposition takes place is an apt one.

Reclamation of saline alkali soils. Green manures are particularly valuable in saline soils, because in comparison with fallow they reduce evaporation from the surface soil and hence the salt content therein. Plants take their water from the sub-soil and shade the surface. Further, when ploughed in, their residues also help to increase the availability of phosphates and trace elements to the succeeding crop owing to the lowering of soil pH brought about by the carbon dioxide produced in the process

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of decomposition. The buffer capacity of the soil is also increased so that negative effects of the high salt concentration may be mitigated. To achieve these objectives, heavy top growth of the green-manuring crops is required. *Dhaincha* (*Sesbania bispinosa*) is one such crop. It withstands salinity and makes moderately good growth on alkali soils. To get the maximum benefit from green-manuring, the crop should be ploughed in at a time when the moisture content of soil is low, so that the initial desiccating reactions may fix the organic complexes, and a highly buffered humified organic residue will help to reduce the concentration of sodium on clay colloids. This has been shown experimentally by Basu in 1937. Mitra *et al.*, in 1955 have also shown in their laboratory experiment that the highest fall of pH and the highest increase in exchangeable calcium in saline alkali soil takes place when a source of calcium (used for reclaiming alkalinity) is incorporated in conjunction with sunnhemp.

PLACE OF GREEN MANURES IN ROTATION

Having seen the response of crops to green-manuring, and its effect on some soil properties, we are now in a position to discuss its place in rotations of wheat, sugarcane, paddy and other crops. Certainly, green manure (Wheat-sugarcane-paddy) rotations have been more remunerative than fallow-wheat-sugarcane-paddy rotation, but utilization of the leguminous crop for fodder or grain and moderate fertilization of subsequent crop with inorganic nitrogen has been more remunerative than rotations having green manure. With the availability of short-duration, high-yielding cereal crops like paddy ('TN.1', 'T.3', 'T.65', 'Adt. 27'), wheat ('Sonora 64', 'Lerma Rojo', 'S.227'), *bajra*, 'H.B.1', *jowar*, 'CSH.1', 'CSH.2' and many hybrids of maize 'Ganga 2', 'Ganga 3' farmers are now adopting multiple croping rotations where green manure *per se* does not have any place, because the 'opportunity cost' of green manure in wheat rotation is equivalent to 40-50 quintal per ha of paddy, bajra or maize. With high prices prevailing in the country more and more of farmers are adopting double cropping of cereals. After the harvest of main crop, short-duration catch crops of legumes like *lobia* in north-western India could be grown which may be utilized for green-manuring. Even here farmers prefer to feed a part of the crop to their cattle.

Surveys carried out by the Institute of Agricultural Research Statistics in West Godavari (Andhra Pradesh), Coimbatore (Tamil Nadu), Barabanki (Uttar Pradesh), Ferozepur (Punjab), Raipur (M.P.), Meerut and Varanasi (U.P.) have shown that in spite of considerable propaganda done by Agricultural Departments, this practice is confined only to certain areas and has not extended in recent years. In Thanjavur district green-manuring is estimated to cover about 20-24 per cent of different rice crops. More than half of this percentage was covered by green-leaf manuring. The practice of leaf manuring will certainly increase or at least will stay static. But in years to come when more and more short-duration, high-yielding hybrids and varieties of cereals will become available as a result of research, cropping patterns involving more and more cereals in a year will come. Our conceptions of rotations have undergone considerable change during the past two decades. The indispensibility of legumes has been challenged in the post-World War II period, because what legumes did, inorganic nitrogen is doing it now in a cheaper way. With legumes dislodged from their pivotal position, green manure will also lose its place. The process has already started in this country. Green-manuring may be used under special circumstances to reclaim alkaline soil or as a source of nitrogen. But in the present price structure it will be a very costly source of nitrogen. As long as our fertilizer industry has not flourished to cope with the need of our intensive crop production this practice will be talked about but cheap nitrogen applied with crop residues will increase the yield of crops and sustain the fertility of the soil. Green-manuring will not be able to compete with this practice.

CHAPTER IV

ORGANIC MANURES (OTHERS)

FARMYARD MANURE

FARMYARD manure is the oldest manure used by man ever since he took to agriculture. It has stood the test of time and is still the most popular of all manures. It consists mainly of vegetable substances mixed with animal dung and urine. It, therefore, contains all the elements present in the plant itself and affords a very suitable means of restoring to the soil the ingredients removed from it by the crop. A part of the unutilized portion of the crop is, thus, returned to the soil to provide nutrients for the benefit of the succeeding crop.

The preparation of farmyard manure offers one of the best means of utilizing farm and other agricultural wastes and simultaneous production of humus in which our soils are so deficient. Unfortunately, the importance and value of this manure have not been sufficiently realized in this country. A good proportion of the fertilizing ingredients contained in it are allowed to be wasted through improper handling, storage, use, etc., with the result that the farmyard manure prepared and used by our farmers at present is of reduced value in increasing crop production. The study of the method of production, care, management and treatment of the manure carried out at a number of Government farms and experimental stations, and the large number of results obtained show that farmyard manure when properly prepared can give increased yields ranging from 10–60 per cent. Still better results can be obtained when it is used in combination with other cultural practices, such as improved seed, proper crop rotation and supplementary fertilizers, that constitute good soil management.

COMPOSITION

Farmyard manure is made up of three types of substances, viz. the solid excreta or dung of animals, the liquid excreta or urine, and straw or other vegetable refuse used as litter. Its composition varies according to the composition of these substances and the proportion in which they are present. In India no litter or very little, if at all, is used. Almost the whole of the urine is wasted as it is not properly collected. Hence, farmyard manure, as prepared in the country, consists almost entirely of cattle-dung mixed with farm refuse, like stalks and stubble. It also contains variable quantities of household wastes, chiefly ash.

Solid excreta. Dung consists mainly of that portion of the food that has not been digested or only partially digested by the animal. It also contains living and dead bacterial cells, which contain nearly half the nitrogen of the dung. Its manurial value depends on the quantity of nitrogen, phosphoric acid and potash it contains, the quantity being dependent on several factors, like type, age, breed and condition of the animal, and the nature of food eaten by it (Table 11).

TABLE 11. AVERAGE NUTRIENT CONTENT OF THE DUNG OF FARM ANIMALS

(Per cent on original matter)

	Horse	Cattle	Buffalo	Sheep	Pig	Poultry
Water ..	76.5	82.4	81.1	61.9	80.7	57.0
Organic matter ..	21.0	15.2	12.7	33.1	17.0	29.3
Mineral matter ..	3.9	3.6	5.3	4.7	3.0	..
Nitrogen ..	0.47	0.30	0.26	0.70	0.59	1.46
Phosphoric acid (P_2O_5) ..	0.30	0.18	0.18	0.51	0.46	1.17
Potash (K_2O) ..	0.30	0.18	0.17	0.29	0.43	0.62
Lime (CaO) ..	0.17	0.36	0.46	0.46	0.09	..

Poultry manure is the richest of all. The urinary excretion of the poultry is semi-solid and is voided mixed with the solid excreta. It is highly concentrated, containing the largest amounts of organic matter and the three manurial ingredients. Sheep-dung comes next, but is very poor in potash. Cattle- and buffalo-dung contain the largest amount of water and are the poorest in manurial ingredients.

A cow or a buffalo excretes much more dung than a horse or a sheep (Table 12). The poor quality of cattle-dung is, thus, compensated for by its greater quantity. A bullock excretes about 14–18 kg and a buffalo 18–23 kg dung everyday (Table 12).

The dung of a young growing animal is poorer in manurial ingredients than that of an adult animal. A working animal excretes dung of a richer quality than an animal at rest. Similarly, the dung of a milking cow is poorer than that of a dry cow.

TABLE 12. AVERAGE QUANTITY OF DUNG AND URINE EXCRETED BY DIFFERENT ANIMALS

Type of animal	Quantity excreted per day*		Type of animal	Av. live wt	Quantity excreted at night (15 hr)	
	Dung (kg)	Urine (kg)		(kg)	Dung (kg)	Urine (kg)
Horse ..	16.1	3.6	Cow (cultivator's)	172	2.8	1.31
Cattle ..	23.5	9.0	Bullock (Govt. farm)	279	3.8	1.4
Sheep ..	1.13	0.6	Breeding bull (Govt. farm)	530	7.7	4.5
Pig ..	2.7	1.5	She-buffalo	374	5.3	2.2
Poultry ..	0.04	..	He-buffalo	617	7.7	4.5

* American data.

The constituents of the dung of farm animals are not in a condition to serve the immediate needs of the crop. The nitrogenous compounds are mainly present as insoluble proteins that have already resisted digestion in the animal body and hence they are unavailable. The dung must, therefore, undergo further decomposition before its manurial ingredients become available.

Liquid excreta. Composition of the urine of various animals is given in Table 13. The urine has higher water, nitrogen and potash contents than that of the dung, but it contains very little phosphoric acid.

TABLE 13. AVERAGE NUTRIENT CONTENT OF URINE OF VARIOUS ANIMALS

(Per cent on original matter)

	Horse	Cattle	Buffalo	Sheep	Pig
Water ..	89.6	92.6	81.0	86.3	96.6
Organic matter ..	8.0	4.8	..	9.3	1.5
Mineral matter ..	8.0	2.1	..	4.6	1.0
Nitrogen ..	1.29	1.21	0.62	1.47	0.38
Phosphoric acid (P_2O_5)	0.01	0.01	tr.	0.05	0.10
Potash (K_2O) ..	1.39	1.35	1.61	1.96	0.99
Lime (CaO) ..	0.45	0.01	tr.	0.16	0.00

The composition of urine also is dependent on the type of animal, age, condition, etc., and the nature and digestibility of food. Sheep urine, like its dung, is the richest in manurial ingredients. Horse urine comes next. It is at the same time very rich in total mineral matter. Pig and cattle urine are the poorest. The poor quality of cattle urine is made up by its greater quantity.

The solid excreta is richer in phosphoric acid and lime, while the liquid excreta is richer in nitrogen and potash. When taken together dung provides nearly 55 per cent of total nitrogen, almost the whole of phosphoric acid and about 30–35 per cent of total potash excreted by an animal. For achieving best results both should be used together as manure.

Litter. The waste vegetable material put under the animal at night as a bedding is the litter. Besides providing a dry bed and keeping the animal clean, it: (*a*) absorbs urine and prevents it from being drained away and lost; (*b*) dilutes the animal excreta and facilitates their even distribution in the manure; (*c*) regulates the decomposition of the excreta and increases its value both chemically and physically; and (*d*) prevents loss of nitrogen from excreta, especially urine, by widening the carbon-nitrogen ratio. The proportion of litter to total excreta, influences the decomposition of the mixture and the ultimate composition of the manure so produced. Too much litter widens the C-N ratio so disproportionately that the material decomposes very slowly.

The quantity used should be sufficient to give a ratio of about 35–40.

Cereal straws form the most suitable material as litter. They have a high absorptive and retentive capacity for both liquids and gases, and contain small amounts of manurial ingredients. Straw in this country is valued more as cattle feed and is seldom used as litter. Other farm wastes, like groundnut shells, rice husk, dry leaves, etc., serve the same purpose and may be used as litter rather than burning them. Even dry earth is sometimes used as litter mainly to absorb urine when no vegetable material is available. Table 14 gives the nutrient content and absorptive capacity of some of the substances commonly used as litter.

TABLE 14. AVERAGE COMPOSITION OF VEGETABLE SUBSTANCES USED AS LITTER

(Per cent on dry matter)

Substance	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)	Water-absorbing capacity* (kg)
Wheat straw ..	0.43	0.17	0.91	100
Rice straw ..	0.40	0.26	1.16	..
Oat straw ..	0.55	0.24	1.39	..
Barley straw ..	0.44	0.19	1.07	..
Jowar straw ..	0.40	0.23	2.17	..
Bajra straw ..	0.65	0.75	2.50	..
Bean straw ..	1.57	0.74	1.62	127
Dry grass ..	0.28	0.08	0.32	..
Dry leaves (mixed) ..	1.51	0.18	0.57	91
Rice husk ..	0.45	0.25	0.45	..
Groundnut hulls ..	1.75	0.45	1.50	..
Peat ..	0.65	0.09	0.12	272
Sawdust ..	0.24	0.20	0.45	197
Earth ..	0.05	0.10	0.20	23

* Quantity of water retained by 45 kg of material after soaking for 24 hours.

Though sawdust and wood-shavings have a high absorptive capacity, they decompose very slowly on account of their high lignin and resin contents. Hence, they should be used very sparingly. Earth has comparatively low absorptive capacity and the very small amounts of manurial ingredients present in it make it very unsuitable for use as litter, except under very exceptional circumstances. As a very large quantity of earth has to be used, it considerably dilutes the manure and gives a finished product of very low manurial value. Peat has a very high water-absorbing capacity and also absorbs ammonia readily. It is an excellent litter, and should be used wherever available easily and cheaply.

The manurial constituents of litter are present in an unavailable form and become available only after decomposition.

DECOMPOSITION

The animal excreta and litter are not suitable for direct use as manure, as most of its manurial ingredients are present in an unavailable form. However, urine, if collected separately, can be used directly. The dung and litter have to be fermented or decomposed before they become fit for use. Hence, the material is usually stored in heaps or pits where it is allowed to decompose. Under suitable conditions of water supply, air, temperature, food supply and reaction, the micro-organisms (principally fungi, bacteria and actinomycetes) already present in the dung—litter and soil—decompose the material. The decomposition is partly aerobic and partly anaerobic. The proper and successful decomposition of the manure requires the functioning of both types of organisms, and proper regulation of both the processes. During decomposition the usual yellow or green colour of the litter is changed to brown and ultimately dark-brown or black colour; its structural form is converted into a colloidal, slimy, more or less homogenous material, commonly known as humus. A well-decomposed manure has a typical black colour and a loose friable condition. It does not give any obnoxious smell and does not show the presence of the original litter or dung.

Growth requirements of micro-organisms. The success in preparing good quality farmyard manure or compost depends on the creation of a favourable environment for the activities of the micro-organisms in the fermenting heap. The conditions essential for this are proper food supply, moisture, aeration, temperature and reaction.

TABLE 15. PROXIMATE COMPOSITION OF ANIMAL DUNG AND LITTER

(Per cent on dry matter)

Material	Organic matter	Ash	Water-soluble organic matter	Ether-soluble substances	Hemi-celluloses	Cellulose	Lignin	Protein
Horse-dung ..	..	9.11	5.58	1.89	23.52	27.46	14.23	6.81
Cattle-dung ..	..	..	9.50*	3.40	26.01	28.59	17.72	8.28
Sheep-dung† ..	..	17.21	24.92	2.83	18.46	18.72	20.68	25.50
Rice straw ..	80.90	19.07	10.98	3.32	22.93	35.77	11.63	3.14
Wheat straw ..	93.90	6.01	8.15	3.77	26.95	37.84	18.23	2.47
Oat straw ..	92.76	7.13	10.53	6.35	26.61	36.40	18.04	2.71
Barely straw ..	94.78	5.09	11.07	6.07	25.35	40.37	17.85	3.95
Sawdust ..	..	..	0.86*	2.98	9.82	53.64	28.25	1.77
Groundnut shell ..	..	..	1.98*	1.20	42.21	16.82	15.73	14.82

* Total water-soluble substances.

† Includes urine also.

Food supply: The three main components, viz. litter, dung and urine, themselves supply the necessary food nutrients to the micro-organisms. Given the right type of nutrients in proper proportion, the micro-organisms work effectively and convert the complex organic constituents into simple mineral substances that can be utilized by the plant. There are two main types of compounds, nitrogenous and non-nitrogenous, that make up the mixture. Some of the nitrogenous compounds are soluble but the majority are insoluble. The non-nitrogenous compounds consist mainly of proteins already present in dung and litter. Urine, on the other hand, contains soluble nitrogenous compounds chiefly in the form of urea, uric acid, hippuric acid and ammonium salts. The non-nitrogenous substances consist of various carbohydrates (sugar, starch, hemicelluloses, etc.), ether-soluble compounds (fats, waxes, resins, etc.) and lignin. Table 15 gives the proximate composition of dung and litter. Hemicelluloses, cellulose and lignin constitute the major portion and are present to the extent of 60–70 per cent in dung, and 70–90 per cent in litter. In urine, on the other hand, these compounds are absent and the organic matter consists almost entirely of soluble nitrogenous compounds enumerated above.

The rate and nature of decomposition depends on the proportion of non-nitrogenous to nitrogenous compounds present in the mixture, i.e., on C-N ratio. The most suitable C-N ratio is

TABLE 16. CARBON-NITROGEN RATIO OF ANIMAL DUNG AND LITTER

Material	Carbon (per cent)	Nitrogen (per cent)	C-N ratio
Cattle-dung	6.52	0.31	21
Wheat straw	40.0	0.33	124
Oat straw	43.3	0.52	83
Ragi straw	39.5	0.64	62
Barley straw	40.9	0.32	128
Rice straw	40.8	0.46	89
French bean haulms	44.2	1.83	24
Weeds mixed	26.6	1.37	19
Hongay (*Pongamia* sp.) leaves ..	41.1	2.12	19
Sawdust	..	0.11	511

about 40. When the ratio is wider than this decomposition takes place very slowly, and when narrower the decomposition is quick. The C-N ratio of cattle-dung and a few substances commonly used as litter is given in Table 16. The C-N ratio of the dung of farm animals varies from 20 to 25, except in the case of poultry manure whose C-N ratio is very narrow, being 5 to 10. The C-N ratio of urine is extremely narrow ranging between 1 and 2 for most farm animals. In the case of litter the ratio varies according to the nature of the substance. Cereal straws in general have a wide ratio, wider than 50. Leguminous straws and haulms have a narrow ratio, about 20. Sawdust and wood-shavings, on the other hand, have an extremely wide ratio.

Moisture: The micro-organisms function at their best only in presence of proper amount of water. About 60–70 per cent moisture is considered to be the optimum requirement to start with, and with the advance in decomposition, it diminishes gradually being 30–40 per cent in the finished product. The material containing large quantities of straw or similar fibrous substances can tolerate greater quantities of water. But if it consists largely of fine materials, like chaff, which get soggy or compact on wetting, it is better to have less moisture to start with.

Excess of moisture prevents the temperature from rising high and retards decomposition, resulting in loss of a part of the soluble plant nutrients through leaching and drainage. Further, waterlogging leads to putrefactive decomposition. Hence, in regions receiving heavy rainfall, it is advisable to store the manure or prepare compost in heaps above ground.

In the absence of sufficient moisture microbial activity ceases and the decomposition practically comes to an end. More often it is the lack of moisture rather than an excess that is responsible for the poor quality of manure prepared in the country. Addition of sufficient moisture in the beginning and its conservation by storing the manure or preparing the compost in pits, especially where water is not easily available, is the only way to keep the microbial activity going.

Aeration: Proper aeration is necessary for the action of the aerobic organisms which hasten fermentation. Under restricted air supply the decomposition is slow but more regular. In the proper rotting of the manure both types of decomposition should be fostered. While filling the pit, the material should not be compacted too tight. This will ensure aerobic conditions in the centre of the pit. Even in a heap where decomposition is

predominantly aerobic, anaerobic fermentation takes place due to the fact that the evolution of carbon dioxide in large quantities excludes the atmospheric oxygen gaining access to the pores and open spaces in the heap. Hence there is the necessity of turning the heap periodically. Most of the microbial processes are oxidative and, hence, a free supply of oxygen is necessary. Excessive watering, compaction, use of large quantities of fine and green materials as litter, and unusually high and big heaps all lead to poor aeration. Under aerobic conditions, there is a rapid oxidation of organic matter and conversion of ammonia to nitrate. Under anaerobic conditions the rate of oxidation is slow, there is greater conservation of organic matter, and nitrate formation is almost completely absent.

Temperature: Under the optimum conditions of air, moisture and food supply, there is a rapid increase in temperature in the manure heap or pit. The temperature usually rises to 50°-60°C, and even to 70°C. The high temperature destroys weed seeds, maggots, worms, pathogenic bacteria, etc., prevents fly breeding, and makes the manure safe from hygienic point of view. When the manure is prepared in pits or trenches, the rise in temperature is not as high as in heaps, but is maintained for a longer period.

Reaction: The micro-organisms liberate certain organic acids during the course of decomposition which, if allowed to accumulate, retard fermentation and sometimes even stop it completely. Hence, it is necessary to control the reaction of the material. A neutral or slightly alkaline reaction, between pH 7.0 and 7.5, is considered the most suitable. The addition of alkaline substances, like lime and wood-ashes, neutralizes the excess acidity and helps to maintain a neutral reaction. Since in the preparation of farmyard manure it is a common practice to add household ashes to the manure pit, it is not necessary to add additional alkaline substances. While preparing synthetic farmyard manure with ammonium sulphate the addition of ground limestone at the rate of 5 per cent of the weight of vegetable residues is sufficient to neutralize excess acidity. In the preparation of compost the addition of wood-ashes and soil serves the same purpose. The soil not only neutralizes the acidity but also acts as a buffer.

Changes during decomposition. The most important changes that take place when the material is stored in heap or pit is the breakdown and disappearance of fats and carbohydrates, and the mineralization of nitrogenous compounds. The sugars, hemicelluloses and cellulose are broken down, the first much more quickly than the other two, to organic acids which are further decomposed to carbon dioxide and water. The soluble nitrogenous compounds are converted to ammonia, nitrites and nitrates. Some of the fats and fatty substances are also broken down to organic acids at first and then to carbon dioxide and water. Proteins undergo hydrolysis and liberate amino acids which are next converted to ammonia. Lignin, waxes, resins and some proteins which are more resistant to decomposition remain as such or, as is more likely, are converted into what are known as 'altered' products due to slow or partial oxidation. At the same time the micro-organisms synthesize new cell protoplasm and build up fresh microbial tissues from carbon, nitrogen, phosphorus, etc., liberated during the breakdown. In this way new carbonaceous and nitrogenous compounds are formed. The altered lignin and proteins of dung, litter, or other plant residues together with the microbial proteins are gradually transformed by chemical and biochemical reactions into the dark-cloured amorphous mass, the humus. The rate, nature and amount of humus formation, therefore, depends on the nature and proportion of animal excreta, litter and other plant residues, type of micro-organisms, and environmental factors, such as aeration, moisture and reaction. Though the humus so formed is the more stable product of decomposition it is not absolutely resistant. It also undergoes decomposition, but at a much slower rate after the manure is added to the soil.

As a result of decomposition there is considerable reduction in the bulk of the manure owing to the disappearance of various compounds in the form of carbon dioxide, water vapour and other gases. Nearly 50 per cent of the organic matter is lost when the material has decomposed thoroughly and C–N ratio of the resultant product comes down to about 20 or a little less.

If the material is allowed to decompose under waterlogged conditions, i.e., strictly anaerobic conditions, the carbohydrates produce, in addition to carbon dioxide, two other gases, viz. marsh gas or methane and hydrogen. The proteins, under these conditions, undergo putrefaction and some of them are converted to foul-smelling gases and substances, e.g., sulphuretted hydrogen, phosphoretted hydrogen, indole and skatole. Some of the other nitrogenous compounds, like amides, amines, ammonia and nitrates, undergo reduction as a result of which they are converted to gaseous nitrogen.

Under partially anaerobic conditions there is an accumulation of intermediate products of decomposition. The various organic acids so liberated combine with ammonia to form ammonium salts and prevent the loss of ammonia by volatilization. The acids also lower the pH of the manure and make it less alkaline. There is no nitrate formation under such conditions. The loss of organic matter is considerably reduced. Hence, there is a greater conservation of organic matter and nitrogen, and a greater production of manure than under aerobic decomposition.

Loss of nutrients. Apart from the inevitable loss of a part of the organic matter during the process of decomposition, there is considerable loss of fertilizing elements from the manure both before and during decomposition. The extent of loss is highly variable. It is estimated that about 50 per cent of organic matter, nitrogen and potash and about 30 per cent of phosphoric acid are lost even when the manure is stored and preserved very carefully.

The loss of nitrogen begins with the loss of urine in the stable or byre through seepage and leaching. In stables with *katcha* floor much of the urine soaks into the ground or flows away for want of proper collecting arrangement. A part of the urine can be retrieved if the floor is dug up from time to time and the moist earth returned to the manure pit. A better procedure would be to cover it with loose earth so that it absorbs urine readily and to remove the urine-containing earth periodically to the pit. It is, however, open to objection as it dilutes the manure with the result that its fertilizing value is often considerably reduced. This method should, therefore, be used under exceptional conditions only.

In stable having *pucca* floor a part of the urine is lost in drains, especially if the amount of litter used is not sufficient to absorb all the urine. Collecting it in cistern at the end of the drain and spreading it on dung and litter in the manure pit or heap helps to recover most of the urine. The urine can also be preserved by spreading some more litter under the cattle at night.

Urine nitrogen suffers a much greater loss by volatilization, as urea is broken down to ammonia and carbon dioxide very rapidly. The volatilization is increased by increase in temperature, alkalinity and drying. This loss can be prevented by spreading superphosphate or gypsum on the stable floor or drains at the rate of about 0.5 to 1 kg per animal per day. It helps to prevent the loss of ammonia by fixing it as ammonium sulphate. The amount of superphosphate required at this rate and its cost, however, precludes its use on any extended scale, except in big dairies. If urine is collected in a cistern a layer of oil on top of the liquid helps to prevent the loss. During the early stages of decomposition also the loss of urea nitrogen, through volatilization, takes place. The fermentation being highly aerobic, it is unfavourable for the accumulation of organic acids; due to this the ammonia that is evolved remains unfixed and escapes. Excluding the air by compaction to encourage acid fermentation helps to retain the ammonia.

The third source of loss is as free nitrogen. Gaseous nitrogen is evolved when the manure pile is made very compact or gets water-logged due to excess water. Both these conditions should be avoided. Yet another source of loss of nitrogen is through leaching in the form of liquid that oozes out from the manure heap or pit. This liquid contains not only soluble nitrogen but also phosphates and potash. The oozing of the liquid is very often due to over-watering. The loss can be reduced if the liquid is collected as it comes out and spreads over the material, or applied direct to the field after mixing with water. In the case of manure prepared in pits, provided with a *pucca* flooring and suitable drains to collect the liquid as it accumulates at the bottom helps to reduce the loss. The loss can also be minimized by adding more litter or vegetable refuse to absorb excess water. This loss is especially great in heavy rainfall regions. In such places the heaps or pits should in addition be suitably protected.

Important losses of ammonia occur even after the manure is spread in the field, especially if it is allowed to remain in heaps. High temperature and windy weather further increase the loss. The best course is to spread the manure and immediately mix it with the soil without allowing it to get dry.

VALUE AND FUNCTIONS

The value of farmyard manure is many sided. It supplies fertilizing elements, improves the physical condition of the soil and encourages soil-microbial activity. As it consists of materials derived from vegetable substances it suppplies all the major as well as minor elements to the crop. Farmyard manure, however, contains very small quantities of these elements. This is especially true in the case of the three major nutrients, viz. nitrogen, phosphoric acid and potash (Table 17). At the rate at which it is normaly applied to the soil, the quantities of N,P, and K supplied by the manure are not sufficient to ensure a high level of crop production. Besides, only a small fraction of these nutrients is immediately available for the requirement of the crop. It is estimated that 30–40 per cent of nitrogen, 20–25 per cent of phosphoric acid, and 50–70 per cent of potash are available to the growing crop during the year of application. The proportion in which these nutrients are present is also not the best for the requirement of crops.

The farmyard manure is very poor in fertilizing elements and has highly variable composition. The N, P, K contents vary widely from sample to sample (Table 17). The large variation in composition makes it a manure of doubtful quality. Judging on the basis of its major plant nutrient contents, a large majority of the samples of farmyard manure prepared in the country are of poor quality. The farmyard manure is, however, a good source for the supply of micronutrients (Table 18).

TABLE 17. AVERAGE COMPOSITION AND RANGE IN VARIATION IN COMPOSITION OF FARMYARD MANURE

(Per cent on dry matter)

	Minimum	Maximum	Average
Organic matter	8.54	58.60	31.67
Mineral matter	54.19	91.46	73.40
Nitrogen	0.35	1.88	0.93
Phosphoric acid (P_2O_5) ..	0.12	2.40	1.00
Potash (K_2O)	0.17	2.42	1.31
Lime (CaO)	1.71	11.02	5.74
Magnesia (MgO)	0.58	2.19	1.13
Organic carbon (C)	1.49	30.90	11.84
C-N ratio	4.5	18.30	9.50
pH value	7.20	7.90	7.36

The value of farmyard manure lies more in the organic matter or humus that it contains. It is through humus that it exerts a profound effect on the physical and physico-chemical properties of the soil. It improves the structure of both sandy and clayey soils. With the improvement in structure, other physical properties, such as aeration, permeability, drainage and resistance to erosion, are also improved. It regulates soil temperature and does not allow the soil to get too hot or too cold. It improves the water-holding capacity, increases the ion-adsorbing and ion-exchange capacities, enhances the buffering power and delays the fixation of phosphoric acid in soil.

TABLE 18. MICRO-NUTRIENT CONTENTS OF FARMYARD MANURE
(Parts per million on dry matter)

	Minimum	Maximum	Average
Copper (Cu)	1.89	8.06	4.63
Zinc (Zn)	2.41	10.81	5.26
Manganese (Mn)	47.90	100.70	83.65
Boron (B)	0.03	0.11	0.06

The addition of farmyard manure helps to increase soil fertility by creating chemical and physical conditions more favourable to the activities of the soil micro-organisms. It serves as food for the micro-organisms and is the main source of supply of carbon and nitrogen. It also meets their energy requirement. As a result of the microbial activities large volumes of carbon dioxide are evolved which, on solution in soil water, bring the insoluble soil minerals into solution. Farmyard manure thus helps to increase the quantity of available plant nutrients in the soil. The metabolic activity of the micro-organisms produces certain slimy substances which bring about the aggregation of soil particles and produce a crumb structure.

By virtue of all these properties farmyard manure creates conditions for the successful use of inorganic fertilizers. The value of farmyard manure has also been attributed to the presence and|or production of phytohormones or plant growth-regulating substances, such as creatinine and indole-acetic acid.

Another important feature of farmyard manure is its residual value. The effect of farmyard manure has been found to last for a number of years. This is partly due to the slow liberation of manurial nutrients, especially nitrogen and phosphoric acid, and partly due to the improvement in physical and biological characters of the soil as mentioned above. The manurial ingredients are present in organic combination and become available only as they are slowly mineralized in the soil. The residual effect lasts for two to three years before the effect of the manure is fully exhausted. Though this is true for temperate regions, it is doubtful if it has any substantial residual effect in hot regions, where almost the whole of the organic matter added to the soil disappears in about one year due to its very rapid decomposition.

METHOD OF PREPARATION

Present practice. The present method of preparing farmyard manure is very crude and inefficient. The common practice is to throw cattle-dung and other farm and household refuse into a pit specially dug for the purpose. The quantity of dung utilized for the purpose is comparatively very little. A good deal of the material excreted by animals in fields or uncultivated ground is practically lost. From the portion collected at night only that which is surplus to the farmer's fuel requirement and other needs is usually returned to the pit. The dung added to the pit is not uniformly mixed with urine and litter. Lumps of dung remain as such for long periods.

Almost the whole of the cattle urine is wasted and no attempt is made to collect it systematically. It is usually allowed to be absorbed by soil where the cattle are tied for the night. Occasionally the soil is dug out and thrown into the manure pit. Some farmers allow it to run into the manure pit through a gutter, but no attempt is made to distribute it evenly over the manure heap.

In this country the cattle are not usually provided with bedding at night; hence, there is no litter which can be utilized for mixing with dung and urine. Whatever straw and remnants of other fodder that are not consumed by the animals are collected every day and thrown into the pit. Seasonally, farm refuses like stubble, stalks, haulms, hulls, weeds and other farm wastes are added to the manure pit. Household and other ashes also form component of the materials added to the pit from time to time.

The materials are usually dumped in one corner of the pit, which is filled up gradually over a period of time. No attempt is made to spread them evenly. The pit itself may be of any size, sometimes as deep as 2.4 to 3.0 m. No water is usually added except what it receives during rainfall. The pit, being open and unprotected, very often gets filled with rain, runoff and storm waters. For a major part of the monsoon the material lies submerged in water or remains over-wet. In summer, on the other hand, the material gets dried, especially the portion that is exposed to the surface.

Due to these reasons the decomposition is fitful and very uneven. Enormous losses of fertilizing elements take place during storage and fermentation and the resultant manure is very poor in quality. Even after it is spread in the field serious losses of nitrogen occur, as the manure is not mixed with the soil immediately but allowed to remain in heaps for varying periods of time.

Preparation of good-quality farmyard manure. To obtain farmyard manure of good quality:

1. prepare a pit of suitable size;
2. make the maximum use of cattle-dung, urine and vegetable wastes;
3. spread the materials evenly in the pit, wetting them with water if necessary, each time; and
4. protect the material in the pit from rain and sun.

The pit should neither be too big nor too small. Ordinarily not more than 0.9 m deep and 1.8 to 2.4 m wide. The length should depend on the quantity of material expected to be put in it everyday or during a season. It is better to have two or more small pits than one long pit. It should be located at a site not likely to be submerged due to runoff or flooding. In low-lying areas the pit should be properly protected by suitable bunds, preferably a brick-lined pit with cement floor to prevent the soluble nutrients being lost underground by leaching and drainage.

Dung and urine are the most valuable components of farmyard manure. Every effort should be made to collect the excreta as completely as possible. As much of the dung and urine excreted during the day is lost and is irrecoverable, all the dung and particularly urine voided at night should be scrupulously collected and utilized for preparing the manure. One of the best ways is to spread some vegetable material of good absorbing properties as litter or bedding for the cattle. Wherever this is not feasible a layer of loose earth spread under the feet of cattle will serve the same purpose. The earth soaked with urine should be scraped and removed to the manure pit every week or fortnight and spread evenly over the other materials.

All farm and household wastes, like stalks and stems, leaves, weeds, refuse and ash should be methodically collected and added to the pit after mixing them properly with dung and urine.

The various materials so collected should be spread evenly in the pit, preferably layer by layer. Depending on the size of the pit and the quantity of material available it should be spread evenly so as to cover the bottom of the pit as completely as possible. When the quantity of the material is too small or the pit is too long, it is better to fill it compartment by compartment (described under the Bangalore Method of preparing compost). The material, if dry, should be watered so as to keep it moist but not wet.

Protecting the material in the pit from rain and sun is very essential. This is best done by providing a roof over the pit.

USE AND EFFECT

Use. Farmyard manure can be applied to all crops and all types of soils. In order to be of real utility there must be adequate moisture in the soil and sufficient time must be allowed, about two to four weeks before sowing, for the plant nutrients to be converted into an assimilable form. There is danger in applying it too early, as some of the soluble plant nutrients are likely to be lost by leaching in rainy season or by volatilization during hot weather. It should be spread evenly in the field instead of putting it up in small heaps, and mixing with the soil immediately. Well-rotted manure may be applied just prior to sowing.

The quantity to be applied to the soil is governed by the environmental conditions. For crops grown in dry areas, where the rainfall is less than 76 cm, 7 to 12 cartloads of manure per hectare are sufficient. When sufficient farmyard manure is not available, it may be applied to a part of the field, say one-third or one-fourth the area, every year so that it covers the whole field every three or four years. The dose may be increased to 20 to 25 cartloads in areas of heavier rainfall. For irrigated crops or in areas of very heavy rainfall the dose may be increased to 40–80 cartloads per hectare.

Fresh *vs.* rotted farmyard manure. Fresh farmyard manure when added to the soil does not liberate any of the fertilizing elements in available form. Its main value lies in the coarse organic matter that it contains. The influence of coarse organic matter on the physical character of the soil is very great. This is especially so in soils of heavy texture. It increases their pore space and makes them more open and permeable.

Fresh farmyard manure, containing litter, should not be used as it has a wide C-N ratio and lacks sufficient soluble nitrogen to meet the requirements of the micro-organisms to decompose the large amount of carbonaceous material. Hence, they utilize the nitrates and other soluble nitrogenous compounds present in the soil and compete with the growing crop, preventing it from utilizing the available nitrogen. If fresh manure has to be used it must be applied sufficiently in advance to allow proper decomposition, or to add some soluble nitrogen to it at the rate of about 0.5–1.0 per cent on the weight of the dry straw or litter, so that it does not starve the crop of soluble nitrogen.

The use of fresh farmyard manure is, however, very restricted due to a number of physical limitations: daily collection, transport, etc.

It is best to use farmyard manure after it has properly rotted. There is no danger of its starving the crop of soluble nitrogen even if it is applied as a top-dressing.

In light sandy soils it is advisable to apply decomposed rather than the fresh manure, as these are already porous and further 'opening' would be harmful. The decomposed manure reduces permeability, increases water-holding and retention capacity, and improves structure and other physical characteristics of light sandy soils.

Effect. The effect of farmyard manure varies with the quantity and quality of the manure applied, time and method of application, crop to which it is applied and other factors, such as water supply. In general, in humid climates or under irigation, the manure gives moderate to large increases in yield of most crops. Even in regions of low rainfall, or where no irrigation is practised, farmyard manure gives increased yields but the increase is of a low order.

Farmyard manure is low in phosphoric acid as compared to nitrogen and potash. To overcome this deficiency the addition of superphosphate or rock phosphate has been recommended. If no superphosphate has been spread on the byre floor or in gutters or drains to prevent the volatilization of ammonia, it is recommended that single superphosphate may be mixed with the manure at the rate of 19–22 kg per 1,016 kg before the manure is carted to the field. It may as well be added to the manure in the pit where it is stored to decompose by sprinkling small quantities at each filling. This treatment has been found to increase the effectiveness of the manure.

ARTIFICIAL OR SYNTHETIC FARMYARD MANURE

Synthetic farmyard manure is a bulky organic manure resembling ordinary farmyard manure produced without the agency of farm animals. The process of preparing synthetic farmyard manure from straw was first discovered and patented in England and is known as the ADCO process of manufacturing artificial farmyard manure. The method is now applicable to all kinds of plant residues and farm wastes. When a plant residue is treated with a solution of a nitrogenous compound, like ammonium sulphate or calcium cyanamide, it undergoes fermentation and gives rise to a product very similar to natural farmyard manure. The addition of phosphate and potash along with soluble nitrogen makes the finished product more balanced in manurial value. Under suitable conditions of moisture, air supply and reaction the micro-organisms already present on the plant residues bring about a rapid decomposition in the presence of the soluble nitrogen, as a result of which sugars, starch, hemicelluloses and cellulose of the plant residue disappear while lignin, waxes, proteins, etc., are converted into humus. The soluble nitrogen is fixed or immobilized into insoluble compounds as the protoplasm of the microbial cells. The insoluble nitrogen is later ammonified and then nitrified when the manure is applied to the soil.

Each plant residue requires a minimum amount of soluble nitrogen to bring about its rapid decomposition. In the case of most straws, which contain on an average 0.4 per cent nitrogen and 45 per cent carbon, the additional nitrogen required is 0.75 part per 100 parts of the dry material. This gives a C-N ratio of about 40 : 1 to start with. The additional nitrogen so required is known as the nitrogen factor. Each plant residue has a different nitrogen factor depending on its nitrogen and carbon contents. Ordinarily a material low in nitrogen has a high nitrogen factor. Table 19 gives the carbon and nitrogen contents of some common plant residues and farm wastes. Materials like maize stalk and *katcha* grass which are rich in nitrogen and have a narrow C-N ratio require very little additional nitrogen, while sugarcane trash, cotton stalks, etc., require large quantities of additional soluble nitrogen for rapid decomposition.

In hot countries like ours it is advisable to substitute ammonium sulphate or similar other readily available compounds by a slowly available nitrogenous material like bone-meal, bloodmeal, oilcakes, or even green leguminous plants. The use of soluble nitrogenous substances leads to a heavy loss of nitrogen during the early stages of decomposition which is considerably reduced when slowly available nitrogenous substances are used.

TABLE 19. CARBON AND NITROGEN CONTENTS OF SOME PLANT RESIDUES

(Per cent on dry material)

	Carbon	Nitrogen	C-N ratio
Rice straw	40.8	0.46	89
Wheat straw	40.0	0.33	124
Oat straw	43.3	0.52	83
Barley straw	40.9	0.32	128
Ragi straw	39.5	0.64	62
Jowar stalks and leaves ..	45.7	0.49	93
Maize stalks and leaves ..	44.2	0.84	53
Cotton stalks	44.6	0.62	72
Sugarcane trash	39.4	0.35	113
Katcha grass	40.1	0.85	47

Method of preparation. Weighed quantities of straw or other plant residues are spread on hard, level ground in a layer 15–30 cm thick, and compacted lightly. A weighed quantity or known volume of water is sprayed on it evenly, and a weighed quantity of ADCO powder or any other starter spread on it uniformly. Over this another layer of straw or vegetable refuse is spread and wetted as before, and ADCO powder or starter applied. A heap about 1.5 to 1.8 m high is, thus, built up and allowed to decompose. As fermentation begins the temperature rises. After about four weeks the heap is turned, the material sprayed with water, and the heap re-built and allowed to decompose further. A second turning is given after another three or four weeks, and a third after another month or so. At every turning water is sprayed as necessary. The manure is ready in about four to six months by which time it has lost about half its bulk. The most essential points are that the material should be kept moist but not over-wet, and the heap should not be disturbed during the first three or four weeks.

Alternatively the manure may be prepared in a pit by spreading the material in it and building up the heap about 30 cm above ground. The material is turned in the pit as mentioned above.

TABLE 20. MANURIAL VALUE OF SYNTHETIC FARMYARD MANURE

Manure prepared from	Moisture	Organic matter	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)	Nature of starter
Per cent on original matter						
Wheat straw ..	80.0	13.56	0.58	0.41	0.18	ADCO powder
Maize stalks ..	72.4	16.25	0.55	0.36	0.28	
Sugarcane trash ..	74.0	..	0.71	0.47	0.34	
Banana leaves ..	89.1	8.18	0.29	..	..	
Per cent on dry matter						
Paddy straw ..	50 to 70	..	1.59	1.34	3.37	Bone-meal and cattle-dung
Dry weeds, chiefly grass		..	1.90	0.55	1.09	
Lantana stalks and leaves		..	1.55	0.52	1.07	
Cotton waste and groundnut husk ..		..	1.62	1.04	1.26	

Manurial value. Treated in this way, any farm refuse like cereal straws, maize and *jowar* stubble, sugarcane trash, and banana stems and leaves, can be converted into manure. The manure so prepared is very much like common farmyard manure in appearance, consistency and manurial value. The composition of synthetic farmyard manure prepared from some of the common farm wastes is shown in Table 20.

Synthetic farmyard manure can be prepared with advantage in tracts or on farms, where the number of cattle is not sufficient to give enough dung and urine to prepare ordinary farmyard manure. It can also be prepared in places where large quantities of organic farm wastes are available for disposal. It is better to convert these wastes into a useful manure than to burn them as is very often done. The manure so prepared can be used in the same way as ordinary farmyard manure, and has been found to be equally effective for all crops.

COMPOST

Compost making is the process of decomposing plant residues in a heap or pit rather than in the soil with a view to bringing the plant nutrient elements in a more readily available form. Thus, it prepares the food material for the crop outside the field and, at the same time, eliminates the unwanted readily oxidisable constituents of the plant residues. If these residues are applied direct to the land without pretreatment they are likely to be injurious to the succeeding crop by robbing the soil of its soluble nitrogen.

The process of composting is also useful in converting harmful waste products, like nightsoil, rubbish and sewage, into an innocuous product that is safe to handle and use. Most of the pathogenic organisms present in these wastes are destroyed by the high temperature generated during the process. The principles invloved and the factors operating in the successful preparation of compost are the same as those described under farmyard manure and synthetic farmyard manure. The final product in either case resembles ordinary farmyard manure in appearance, properties and manurial value.

Composting of farm wastes. Farm compost may be prepared either by the Indore Method or by the Bangalore Method. The former is a fully aerobic process, while the latter is aerobic to start with, followed by anaerobic decomposition.

Indore Method: The materials needed for preparing compost by this method are mixed plant residues, animal dung, urine earth, wood-ashes, water and air. All vegetable wastes available on the farm, like weeds, stalks and stems, fallen leaves, prunings, chaff, remnants of fodder and green manure, are collected and stacked in a pile. Hard woody materials, like cotton and *tur* stalks, stumps and stubble are first spread on the farm road and crushed under the farm traffic before they are stacked. Such hard materials should not form more than about 10 per cent of the total plant residues. Substances, like banana stem and leaves, are split lengthwise and chopped into small pieces. Green materials that are soft and succulent are allowed to wilt for two or three days to get rid of excess moisture before they are stacked. They tend to pack closely if they are used in the fresh state. While stacking each material is spread in layers of about 15 cm thickness till the heap is about 1.2 to 1.5 m high. The mixture of different kinds of vegetable residues ensures more efficient decomposition than when the materials are rotted separately.

The heap is cut in vertical slices to ensure proper mixing, and the mixed plant residues are spread under the feet of the cattle in the shed as bedding for the night. It is spread at the rate of about 20–25 kg per pair of cattle. Next morning, the bedding along with the dung, etc., is taken to the pit where compost is to be prepared. Patches of floor mixed with urine are scraped and the urine earth added to the soiled bedding material before it is taken to the pit. The patches are then filled with new soil and the floor rammed if necessary. Alternatively, the earth under the animals may be dug out every three months and stored under shade for further use. It should be crushed to powder if necessary before use. Fresh earth is added to replace the urine earth and the floor rammed again.

The site selected for the pit should be at a high level so that no storm water gets in nor the water-table rises, and create water-logging in the pit during monsoon. The pit should be about 90 cm deep and 1.8–2.4 m wide with any suitable length, and should be protected by putting a small bund round it. It should be as near the cattle shed as possible or near the source of supply of water, and should have sufficient space between them for the carts to move freely. A *katcha* shed may be erected over it to protect the material during heavy rains. The material brought from the cattle shed is spread evenly in the pits in layers of 7–15 cm. On each layer is spread a slurry made of 4.5 kg of cattle-dung (kept separately), 3.5 kg urine earth, 4.5 kg fungus inoculum (taken from an actively fermenting heap about two-week-old) and 0.5 kg of wood-ash in four gallons of water per pair of cattle. A sufficient quantity of water is sprinkled over the material in the pit to make it moist but not too wet. The pit is filled in this way layer by layer, the layer of bedding material alternating with that of slurry and water. It should not take more than six or seven days to fill the pit in this manner. While filling the pit, care should be taken to see that the material is not trampled or compacted in any way.

The pit is filled till the material is 30 cm above ground level. The whole length of the pit may not be filled, leaving about one-fourth the pit empty to facilitate subsequent turnings. The material is turned three times, the first about 15 days after the charging of the pit commences, the second after another 15 days and the third about a month later. At each turning the material is mixed properly, moistened with water and the heap built again. At the first turning about 4.5 kg of bacterial inoculum (taken from a compost heap that is 30-day-old) is spread over the material and well mixed before it is watered. Though the mixing of the fungal and bacterial inoculum is a recommended practice, it is not strictly necessary as the farm refuses and soil carry all the micro-organisms needed for decomposition. At the third turning, the heap is built on the ground outside the pit, and several such heaps may be joined together to save space and economise water. The compost is ready in about three or four months.

During rains, or in regions of heavy rainfall, the compost may be prepared in heaps above ground that are protected by a *pucca* shed. The heaps may be of any suitable size, not more than 3 m × 3 m, broader at the base than at the top, and ordinarily not more than 90 cm high. The best time to turn the heaps is when the temperature begins to fall. Each time the material is mixed properly, moistened with water, and the heap built up again.

When sufficient nitrogenous material is not available a green manure or leguminous crop like sunnhemp may be grown on the fermenting heap by sowing seeds on the heap at the first turning. The green material is then turned in at the time of the second turning. It may be sown again if necessary, and turned in again at the time of the third turning. The green manure supplies easily available nitrogen and helps to establish the desirable C-N ratio.

The Indore Method suffers from the fact that it demands considerable labour and attention to details with regard to the construction of heaps, proportioning of the various ingredients, frequent turnings, etc. Above all, it requires large quantity of water which makes the process unsuitable for areas of scanty rainfall. In such areas, compost making will have to be restricted to monsoon months only. Even then, special arrangements will have to be made to store rain-water. On account of the large quantities of earth which forms about 50 per cent of the weight of the mature product, the compost is considerably diluted and its manurial value reduced. It also adds to the cost of preparation. The intense aerobic fermentation to which the material is subjected no doubt shortens the period of composting, but it leads to a heavy loss of organic matter and nitrogen.

Bangalore Method: This method overcomes many of the disadvantages of the Indore Method. The material is allowed to remain in the pit or trench throughout the period of decomposition. This eliminates the necessity of turning and watering the material now and then. As the trench is sealed off with mud plaster after it is filled, the water that was used in the beginning is sufficient to complete the process of decomposition as there are no chances of its loss by evaporation. After the initial aerobic decomposition during the first eight to ten days, when there is a great rise in temperature, the material undergoes semi-anaerobic decomposition. Under these conditions, the decomposition is more gradual and slow and it takes a longer time, about six to eight months, for the finished product to be ready. As the farmer generally requires the compost once a year or at the most twice, once in *kharif* and again in *rabi*, the longer time taken for the manure to be ready is no disadvantage.. Under this process there is less loss of organic matter and nitrogen and hence there is a greater production of compost. The manure is at the same time more rich in nitrogen.

TRENCHES: The selection of site for digging trenches and other requirements are just the same as in the case of the Indore Method. The trench should have preferably sloping walls and floor. A slope of 90 cm in the floor is sufficient to prevent waterlogging. The dimensions of the trench are about the same as mentioned under the Indore Method. A length of 6 m is sufficient for two pairs of cattle, 7.6 m up to five pairs, and 9.1 m up to ten pairs. It is better not to have trenches longer than 9.1 m.

Filling the Trench: All the farm refuse is collected and stacked as described under the Indore process. A suitable quantity, about 14–18 kg per pair of cattle, of the mixture is placed under the animals at night. The next morning, the soiled bedding along with the dung and urine earth is taken to the trench after mixing them properly. The trench is filled by sections of 60–120 cm at a time. A temporary movable partition made of bamboo poles and cotton or *tur* stalks is fixed in the trench at the shallower end at a distance of 60 or 120 cm from the wall, thus creating a miniature trench within the larger trench. The distance may be adjusted according to the quantity of bedding available everyday. The bedding is spread evenly in the section after thoroughly mixing it with dung and urine earth. Water equal to 1 or 1-1|2 times the weight of dry residue is sprinkled over it uniformly. Over-watering should be avoided. The section is filled in this way by spreading each day's collection of bedding, dung, etc., over the previous day's material till the heap is 30 to 60 cm above ground level. The filling of the section should be completed in about seven or eight days. The upper surface of the heap is made dome-shaped and covered with mud plaster about 2.5 cm thick.

When the filling of one section is completed, the temporary partition is removed and a similar section made next to it. The new section is filled just the same way as the first and the top covered with mud plaster. The whole trench is filled in this way, section by section, till it is full. No turnings or waterings are necessary after it is once filled and plastered. The compost is ready in about six months.

Manurial value: The manurial value of farm composts prepared by the two methods is shown in Table 21. The manurial value is, in general, equal to that of well-prepared, good-quality farmyard manure. Numerous experiments have been carried out to test the value of the compost in the field. In all cases it has given increased yields, the increase varying from 20 to well over 100 per cent over the control. It is used just the same way as ordinary well-decomposed farmyard manure.

The greatest scope for the manufacture and use of compost lies in the numerous irrigation schemes where water is freely available. Its effect on crop returns is greater under irrigation than under average dry-farming conditions. When used in conjunction with inorganic fertilizers it not only gives much higher yields but also helps to maintain the soil in good healthy condition for the fertilizers to show their best effect.

TABLE 21. MANURIAL VALUE OF FARM COMPOST
(Per cent on dry matter)

	Organic matter	Ash	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)	Lime (CaO)	Organic carbon (C)	C–N ratio
Indore Method								
Mixed farm wastes, Poona ..	28.64	71.35	0.87	0.59	2.22	1.62	12.89	14
Mixed dry residue, Indore ..	20.13	79.86	0.90	0.45	1.95	..	..	11
Cotton stalks, Indore ..	33.91	66.08	1.61	0.48	3.38	..	..	16
Farm compost, Indore (average of 6) ..	20.79	79.37	0.89	0.51	3.05	5.05	..	..
Bangalore Method								
Ragi straw ..	78.52	..	1.24	..	..	..	32.72	26
Dry leaves ..	28.78	..	0.74	..	..	..	17.04	23

NIGHTSOIL AND SEWAGE

Human excreta, both solid and liquid, have a high fertilizing value, greater than that of animal dung and urine. Table 22 shows their composition and manurial value. In China and Japan human excreta is highly prized as a manure, and special efforts are made to collect and store it carefully. The high fertility of the soils of these countries is attributed to the continued use of human excreta as manure for centuries. It is used either directly after diluting it with water or after composting it with farm wastes.

TABLE 22. MANURIAL VALUE OF HUMAN EXCRETA
(Per cent on original material)

Manurial constituent	Human faeces	Human urine	Manurial constituent	Human faeces	Human urine
Moisture ..	75.0	97.0	Potash (K_2O)	0.5	0.2
Organic matter ..	22.1	2.0	Lime (CaO)	1.0	0.3
Mineral matter ..	2.9	1.0	Organic carbon (C)	11.0	0.8
Nitrogen ..	1.5	0.6			
Phosphoric acid (P_2O_5)	1.1	0.1	C-N ratio	7.3	1.3

Attempts are being made, of late in this country, to utilize human faeces and urine as manure. Though urine can be used directly as such nightsoil cannot be used in the fresh state. It has got to be treated to make it innocuous and safe for handling and use. There are several methods of treating nightsoil for this purpose. They are mainly meant for the sanitary and hygienic disposal of the material.

Poudrette system. In this system of disposal of nightsoil, the material is spread in beds or pits, covered with ashes, earth or any other absorbent, and allowed to dry. When spread in shallow beds it takes eight to ten days to dry. It is then taken out and allowed to dry further in the sun. When poudrette is prepared in pits, the nightsoil is spread in alternate layers of earth and it takes six to eight months, sometimes even longer, to dry. The poudrette so prepared has a fairly good fertilizing value (Table 23). However, it still possesses the offensive smell which militates against its more wide-spread use. Hygienically also it is not quite innocuous and safe for handling.

TABLE 23. MANURIAL VALUE OF POUDRETTE
(Per cent on original material)

Manurial constituent	Bed method	Pit method	Range of variation
Moisture	28.10	28.25	..
Nitrogen	1.12	1.80	0.43-2.39
Phosphoric acid (P_2O_5)	0.68	1.93	0.75-3.09
Potash (K_2O)	0.94	1.07	0.42-2.64

From the manurial point of view, this system is highly inefficient as, apart from diluting the manure, it leads to a considerable loss of the fertilizing elements, more especially nitrogen during drying.

Purification system. Most of the cities have now underground sewerage system for the disposal of human wastes. Under this system, the faeces and urine mixed with wash water are conveyed through sewers before they are let out into the sea or river as sewage. The raw or crude sewage consists mainly of water carrying various solids partly in solution and partly in suspension. Apart from sand, silt and grit, much of the solids in suspension consists of colloidal faecal matter.

In many cities the sewage is purified before it is let out so that it does not pollute the river or stream-water. There are several methods of purifying sewage of which the septic tank method, the filter bed or percolation method, and the activated sludge method are the more important ones. They all work on the principal of biological oxidation of organic substances.

In the septic tank method the decomposition is mainly anaerobic, while the filter tank bed method allows aerobic decomposition of the colloidal solids in suspension. In the activated sludge process, the raw sewage is stirred with a large excess of air so that the decomposition takes place under super-aerobic conditions. By whatever method the sewage is purified the resultant products, viz. the effluent and the sludge, can be utilized as manure, as they contain quite good quantities of plant food ingredients.

Raw sewage. Table 24 shows the manurial value of raw sewage. These figures are merely illustrative as the composition of sewage varies considerably. It is rich in all the fertilizing elements. Nearly three-fourths of the nitrogen, half of the phosphoric acid, and almost the whole of potassium are present in a soluble and, hence, readily available form. It is used for irrigating crops either as such or after dilution with water, depending on the amount of solids in solution and suspension the raw sewage contains. Almost all crops have been found to benefit by sewage irrigation. The benefit derived by crops is due to the water as well as the plant nutrients and organic matter supplied by the sewage.

TABLE 24. MANURIAL VALUE OF RAW SEWAGE AND EFFLUENTS OBTAINED BY DIFFERENT METHODS

(Parts per 100,000)

Manurial constituent	Crude sewage			Effluent		
	Bombay	Ahmedabad	Poona	Septic tank, Calcutta	Filter bed, Calcutta	Activated sludge, Bombay
Total solids ..	80.40	..	..	..	..	..
Solids in suspension ..	23.80	41.60	92.50	15.68	7.12	1.00
Total nitrogen ..	1.98	3.85	3.70	2.45	2.10	2.85
Ammoniacal nitrogen ..	1.52	3.20	2.69	2.11	0.21	0.61
Albuminoid nitrogen ..	0.46	0.63	1.01	0.34	0.23	0.08
Nitric nitrogen ..	Nil	0.02	Nil	Nil	1.69	2.16
Phosphoric acid (P_2O_5)	1.75	..	2.17	..	..	..
Potash (K_2O) ..	1.45	..	..	..	..	..

Continuous irrigation with raw sewage is, however, fraught with danger. It spoils the soil and increases the hazards to health associated with the use of nightsoil. The colloidal solids in suspension choke the soil pores and bring about sewage sickness in the soil. After the first few years, when it gives heavy yields, the crop begins to suffer for want of aeration. It also disturbs the distribution of the microbial population in the soil; the protozoan fauna increases at the expense of the bacterial flora. Sewage irrigation should, therefore, be restricted to sandy soils having good underdrainage. Low rainfall and a warm climate are other factors favourable for sewage irrigation. Sewage-irrigated lands should be rested periodically to permit soil recovery. Heavier soils need rest more frequently than loams and other light soils. It should be used after dilution as far as possible.

Sewage-irrigated crops are likely to be injurious to human and animal health. Great care requires to be taken in the case of fodder and vegetables which are consumed uncooked as they are likely to be in direct contact with raw sewage.

In many cities and towns all types of industrial wastes are now disposed of by letting them in sewers. This makes the sewage entirely unsuitable for application to land. Many industrial wastes are known to spoil the soil making it saline, alkaline, or acidic. Unless the industrial waste has been pre-treated to get rid of its obnoxious properties before it is let into sewers and gets mixed with domestic sewage, it is very risky to utilize the sewage for agricultural purposes.

Sewage effluent. When crude sewage is allowed to decompose either aerobically or anaerobically a part of the colloidal matter in suspension is turned into gases, a part is turned crystalloid and goes in solution, and a part is thrown down as residue. The residue is known as sludge and the liquid portion is known as effluent. The nature and composition of the effluent and the sludge vary with the type of decomposition the raw sewage has undergone.

In septic tank treatment where sewage is allowed to remain undisturbed in tanks for a time, it undergoes putrefactive changes as a result of the anaerobic decomposition. Large volumes of combustible gases containing methane and hydrogen are evolved, the albuminous substances are converted to ammonia, and the fatty substances give rise to butyric acid. The effluent, though not as turbid as the original sewage, still contains appreciable quantities of colloidal matter in suspension.

In the filter bed method, the sewage is allowed to percolate through filters, specially constructed for the purpose, when the colloidal matter undergoes aerobic decomposition. As a result of these changes, a part of colloidal matter is oxidised and disappears, a part goes in solution, and the rest becomes granular and is thrown down as sludge, leaving the effluent almost entirely clear. In contrast to the septic tank effluent it has no foul smell, carries very little colloidal matter in suspension, and contains a large part of the nitrogen as nitrates.

In the activated sludge process, where air under pressure is forced through crude sewage, each colloidal particle comes in close contact with a large amount of oxygen, as a result of which almost the whole of the colloidal matter is oxidised leaving very little as sludge. The supernatant effluent is as clear as water, and contains the whole of the nitrogen as nitrates.

TABLE 25. MANURIAL VALUE OF SEWAGE SLUDGE

Manurial constituent	Raw settlement sludge, Delhi (on air-dry material)	Septic tank sludge (on original material)	Simplex-activated sludge, Delhi (on air-dry material)	Activated sludge, Coimbatore (on dry matter)
Moisture	6.68	70.00	13.56	..
Organic matter ..	47.68	19.00	63.97	64.10
Nitrogen	3.14	0.78	6.91	5.88
Phosphoric acid (P_2O_5) ..	1.68	0.31	3.08	3.18
Patash (K_2O) ..	..	0.12	..	0.67
Organic carbon (C)	27.65	..	37.05	..
C-N ratio ..	8.80	..	5.30	..

The composition of the effluents obtained by the different methods is shown in Table 24. The difference is very obvious. The filter bed and activated sludge effluents can be used for irrigation without running any risk, but the septic tank effluent is likely to make the soil sewage sick. The safeguards and precautions mentioned for the use of crude sewage apply to this effluent also if it is to be used for agricultural purposes.

Sewage sludge. The sludge can also be used as manure either as such or after drying. Its fertilizing value lies mainly in its nitrogen, most of which is present in the form of complex proteins or albuminoids. The sludge obtained by the aerobic fermentation is usually richer in nitrogen and phosphoric acid than that obtained by the anaerobic decomposition. Table 25 illustrates the manurial value of sludge obtained by the different methods.

Town compost. This method of disposal of human excreta is suitable for towns and cities which have not yet adopted the sewage purification system. Under this method, all town wastes, like sweepings, garbage, household rubbish, nightsoil, etc., are collected and allowed to decompose in trenches by the Bangalore method. The manurial value of some of these materials, presented in Table 26, is quite high.

TABLE 26. AVERAGE COMPOSITION AND MANURIAL VALUE OF TOWN WASTES

(Per cent on original material)

Material	Moisture	Organic matter	Organic carbon (C)	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)	Lime (CaO)	C-N ratio
Town refuse ..	10	25	12	0.6	0.3	1.0	0.4	25
Nightsoil ..	75	19	9	1.0	0.8	0.4	0.9	9
Animal blood ..	77	19	8	2.6	0.2	0.1	0.4	3
Slaughterhouse-waste (solids) ..	75	18	3	1.6	0.6	0.4	0.6	2

Some of them like nightsoil, animal blood and slaughterhousewaste are rich in nitrogen and phosphoric acid and have a narrow C-N ratio, while town sweepings and refuse are poor in nitrogen and have a wide C-N ratio. All these wastes when composted in trenches yield a first class, bulky, organic manure of high quality. The manure so obtained is quite innocuous and safe to handle and apply to the soil. Large quantities of town

TABLE 27. MANURIAL VALUE OF TOWN COMPOST

	Moisture (per cent on original matter)	Per cent on dry matter							
		Organic matter	Ash	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)	Lime (CaO)	Organic carbon	C-N ratio
Habitation-wastes, Indore ..	10.93	22.30	77.70	0.64	1.12	1.33	25.74	..	..
Municipal-wastes*, Gujarat	36.78	34.61	65.29	1.87	4.29	0.96	5.53	12.01	6.4
Municipal-wastes*, Maharashtra ..	32.32	24.57	75.43	1.19	2.51	0.94	6.98	9.31	7.8
Municipal-wastes*, Karnatak	39.47	32.19	67.81	1.52	2.87	0.88	5.45	12.47	8.2

*Mainly *kachra* and nightsoil

compost are produced every year in the country by all towns and cities having the sewerage system. Many city municipalities utilize the crude sewage and sewage effluent for preparing compost from city refuse and other wastes. On account of the difficulty and high cost of drying sewage sludge some municipalities utilize this residue also for preparing compost. The compost so prepared is quite rich in fertilizing elements. Its nitrogen and phosphoric acid contents are on the whole much greater than those of farm compost or farmyard manure as illustrated in Table 27. In addition to the major plant nutrients, the town compost is well-supplied with micro-nutrients as shown in Table 28.

Town compost gives very high yields of crops grown under irrigation, e.g., vegetables, potatoes, sugarcane, rice, papaya, banana, etc. The dose varies from 11.20 to 22.40 tonnes per hectare for irrigated crops and 6.69 to 11.20 tonnes for crops grown in assured rainfall areas. The dose may be further reduced to 2.24 tonnes per hectare in areas of scantly rainfall. It is used just the same way as ordinary farmyard manure. It does not suffer from the drawbacks and defects pointed out in the case of raw sewage and sewage effluent.

TABLE 28. MICRO-NUTRIENT CONTENTS OF TOWN COMPOST

(Parts per million on dry matter)

Micro-nutrient	Minimum	Maximum	Average
Copper (Cu)	5.44	111.60	29.47
Zinc (Zn)	2.13	11.99	6.34
Manganese (Mn)	25.52	102.20	58.74
Boron (B)	0.04	0.27	0.13

BIOLOGICAL FUEL GAS AND SLURRY

When cellulosic substances, like plant residues, animal dung, etc., are decomposed anaerobically they produce large volumes of combustible gases, chiefly methane and hydrogen, in addition to carbon dioxide. Based on this principle, a satisfactory method of producing fuel gas from cattle-dung under village conditions has been worked out. A simple plant similar to the plants used for digesting sewage for gas production has been designed which can be set up by any farmer at a low cost. The gas can be utilized for cooking, heating, lighting and even for running gas engines and pumps. The plant is simple to operate and requires no additional labour.

The residual slurry left after degestion contains almost the whole of nitrogen, phosphorus and other nutrients present in the cattle-dung, and its manurial value is superior to that of farmyard manure or compost. This method of utilizing animal dung and other farm wastes is very economical as it provides fuel as well as manure to the farmer.

FUEL GAS

Plant

Construction: The plant consists of combined digester and gas-holder. A circular tank built of concrete or masonry serves as a digester in which the material is allowed to ferment. It is constructed partly under and partly above ground. The bottom and walls of the tank are cement plastered to prevent leakage of gas or liquid. A small square tank is built by its side above ground to facilitate charging the digester. Its outlet is connected to the bottom of the digestion tank.

A drum, made of mild steel is inverted into the digestion tank and is kept floating in the fermenting liquid to collect the gas evolved. The drum is held in place by means of angle iron posts mounted on top of the tank. Pulleys, guide wheels and guide channels are provided to allow the drum to rise and fall with the accumulation and consumption of gas. The gas is led from the gas-holder to the burner by means of pipes fitted with valves and safety traps at suitable places.

A number of industrial concerns undertake to supply prefabricated plants or to construct one at site.

Location: The plant should be located somewhere between the house or the place where the gas is to be utilized and the cattle shed or the source of water supply, whichever is convenient. It should be located so as to minimize transportation of dung and water as well as to economize the gas piping. It should be so placed as to receive the maximum amount of sunlight in order to maintain the fermenting material at a high temperature. Nearness to latrine is another consideration if latrine-wastes are utilized for gas production.

Size: The size will depend on the requirement of the individual or the number of cattle at his disposal. It is estimated that the dung of three animals (about 50 kg) would give sufficient gas (about 2.8 m^3) every day to meet the fuel requirements of a farmer for cooking purposes for a family of five members. A digestion tank 3.6 m deep and having 1.5 m inner diameter at top for its first 1.2 m and 1.3 m for the lower 2.4 m is sufficiently big to hold a daily charge of 50 kg of cattle-dung for 30 days. A drum 1.5 m in diameter and 1.2 m in height makes a suitable gas-holder for the above digester.

Charging the digestion tank: About 50 kg of cattle-dung mixed with an equal quantity of water is added to the small tank from where it passes to the bottom of the digester. A slurry made of about 50 kg of actively fermenting dung obtained from another bio-gas plant or an equal quantity of sewage of septic tank sludge is added to the digester to provide the inoculum. Gas production takes place in about a week or ten days when another charge of about 250 kg of dung mixed with an equal quantity of water is added to the digester through the small tank. As more gas is evolved, further quantities of dung slurry are added every alternate day till the digester is full. As more gas collects in the gas-holder, the drum slowly rises. The gas-holder is suitably counterpoised to facilitate the collection of gas. When the gas is to be let out, the counterpoise weights are removed and the gas-cocks opened. When the plant is in operation, 50 kg of dung mixed with an equal quantity of water are added daily to the digester. An equal quantity of the digested slurry comes out from the overflow outlet from where it is led into the drying beds.

Effect of climate: The rate of gas production is usually greater in summer than in cold winter months when the production of gas falls down due to the fall in temperature. The optimum atmospheric temperature for maximum gas production lies between 30° and 35°C, while at temperatures below 10°C gas production practically ceases. In order to increase the production of gas during the colder months it is necessary to see that the temperature of the fermenting liquid does not fall appreciably. The exposed or above-ground portion of the digester may be suitably insulated by providing a double-wall jacket and packing it with sawdust, straw, etc. Alternatively, the dung slurry may be warmed to 30° or 35°C before it is added to the tank by utilising a part of the gas, or the wall of the tank may be heated by hot-water or hot-air pipes coiled round it. An actively fermenting manure heap stacked round the exposed part of the digester serves the same purpose. Similar arrangements must be made for heating the tank in cooler regions.

Nature of gas. The gas consists of a mixture of methane hydrogen and carbon dioxide together with small quantities of nitrogen. Methane and hydrogen, which are combustible, form the major bulk, the former constituting 50–60 per cent and the latter 6–10 per cent of the mixture. The gas burns with blue non-luminous flame without smoke, and has a high calorific value equal to that of oil or coal gas. As it does not contain the poisonous carbon monoxide gas, it is safe for use in houses and other enclosed places.

Suitable burners with rose-head or other arrangements for spreading the flame are available in the market. When supplied at a pressure equal to 10–15 cm water-head it can be used for cooking, heating or lighting purposes.

Digested slurry. The residual slurry that comes out of the digestion tank has a manurial value superior to that of farmyard manure. It contains 2.0–2.4 per cent nitrogen (on dry basis), of which about 10–15 per cent is in the form of free ammonia. Almost the whole of the ammonia is lost when the slurry is dried in the sun, bringing down the nitrogen content to about 1.8 per cent. The dry slurry nitrifies readily and when tried on crops on equal nitrogen basis gives better results than farmyard manure. It should not be used, however, in the wet condition as it is likely to be injurious to the crop. When sun-drying is not possible as in rainy season, the wet slurry may be used for composting farm wastes.

Working and maintenance. The plant works automatically if the charging tank, the digested slurry exit pipe, and the drying beds are placed so as to have a downward gradient. It requires no additional labour, and very little attention is needed for its day-to-day working. Hence, the operation charges are low.

The only maintenance cost is for repainting the iron structure once a year and for repairs to the digestion tank, if any.

OILCAKES

Oilcake is the residue left after the oil is extracted from oil-bearing seeds. It contains varying quantities of oil depending upon the process of manufacture employed in treating the oilseed, as shown below:

Process of manufacture	*Oil (per cent)*
Country *ghani*	10–15
Hydraulic press	8–10
Expeller	5–8
Solvent	1–2

The manurial value of oilcake lies mainly in its nitrogen though it contains small quantities of phosphorus and potash as well. It contains far greater quantities of nitrogen than well-prepared farmyard manure or compost. The nitrogen content varies from 3 to well over 9 per cent, depending on the type of oilcake, the amount of oil it contains, and the amount of hull or husk present in it. Seeds, decorticated before extraction, give a product that is more rich in nitrogen than those which are not decorticated.

The C-N ratio of oilcake is usually narrow, being 3–15 for most oilcakes. Because of this, it nitrifies very readily. Nearly 50–80 per cent of its nitrogen is made available in about two to three months. The rate of availability varies with the type of oilcake and the nature of the soil. On the whole, oilcake containing a greater amount of oil decomposes more slowly than that containing less oil.

The plant nutrients present in oilcake are in organic combination. They are liberated in available form only after the oilcake undergoes decomposition in the soil. As it requires a certain amount of moisture for its decomposition, the use of oilcake is limited to irrigated crops or to tracts having a sufficiently high rainfall. It is best used as a top-dressing after the plants have established themselves.

A list of oilcakes together with the average amount of manurial constituents they contain is given in Table 29. Oilcakes are sometimes adulterated with earth, sand, hulls or husks. The higher the proportion of earth or husk, the lower is the manurial value. They should be, therefore, purchased on the basis of a guaranteed nitrogen content. They are quick-acting manures and they show their effects in a week or two after application

TABLE 29. AVERAGE PERCENTAGE COMPOSITION OF OILCAKE.

Type of oilcake	Botanical name of the plant	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)
Castor cake	*Ricinus communis* L.	4.37	1.85	1.39
Coconut cake	*Cocos nucifera* L.	3.02	1.90	1.77
Cottonseed cake (undecorticated)	*Gossypium* spp.	3.99	1.89	1.62
Cottonseed cake (decorticated)	*Gossypium* spp.	6.41	2.89	2.17
Groundnut cake	*Arachis hypogaca* L.	7.29	1.53	1.33
Jambo cake	*Eruca sativa* Mill.	4.95	1.65	1.90
Karanj cake	*Pongamia glabra* Vent.	3.97	0.94	1.27
Linseed cake	*Linum usitatissimum* L.	5.56	1.44	1.28
Mahua cake	*Bassia latifolia* Roxb.	2.51	0.80	1.85
Neem cake	*Azadirachta indica* A. Juss.	5.22	1.08	1.48
Niger cake	*Guizotia abyssinica* Cass.	4.73	1.83	1.31
Rapeseed cake	*Brassica campestris* L.	5.21	1.84	1.19
Safflower cake (undecorticated)	*Carthamus tinctorius* L.	4.92	1.44	1.23
Safflower cake (decorticated)	*Carthamus tinctorius* L.	7.88	2.20	1.92
Sesame cake	*Sesamum indicum* L.	6.22	2.09	1.26
Undi cake	*Calophyllum inophyllum* L.	3.63	1.52	2.05

in the dark-green colour of the leaves. Unlike bulky organic manures they have no residual effect. As edible oilcakes are valued more as cattle feed they are uneconomical for use as manures. The non-edible oilcakes offer a useful source of organic nitrogenous manures for increasing crop yields.

Castor cake is a non-edible oilcake and decomposes comparatively slowly. The rate of availability of its nitrogen is less rapid than that of groundnut cake. Its effect is, therefore, more lasting. In South India, white castor cake has been found to be superior to the black variety. Its rate of nitrification is even greater than that of groundnut cake. Castor cake is said to be a good vermicide against white ants.

Coconut cake is seldom used as manure, except when it becomes mouldy or rancid and unfit for feeding cattle.

Cottonseed cake should form a very useful manure as it is rich in nitrogen and phosphoric acid. It also nitrifies readily. Its use is, however, very limited.

Groundnut cake is very popular with our farmers as a concentrated organic manure. Not only does it contain a very high amount of nitrogen but the availability of nitrogen is also very high. Though the rate of nitrification varies with different soils, it nitrifies to a greater extent than other oilcakes in almost all soils.

Mahua cake is very poor in nitrogen and takes a long time to nitrify. When used as manure, it has got to be applied to the soil two to three months ahead of the sowing time.

Rapeseed or sarson cake is very popular in the north as a concentrated organic nitrogenous manure. It compares favourably with castor, cottonseed, *karanj, til* and *neem* cakes as far as nitrification is concerned.

Karanj and *neem cakes* are non-edible and are used exclusively as manure. Linseed and sesame cakes are prized more as cattle feed and are seldom used as manure. Generally the undecorticated variety of safflower cake is used as manure. As compared to groundnut cake it is rather slow to nitrify though not as slow as castor.

BONES AND BONE-MEAL

Bones form an important source of manure. Ordinarily they are reduced to powder before they are applied to the soil as manure. The finer the powder the more easily its manurial constituents become available. Particles smaller than 2.3 mm in size are considered suitable for use as manure.

Bones consist of calcium phosphate together with some organic matter consisting mainly of fats and proteins. Hence, these are a good source for the supply of lime, phosphoric acid and nitrogen. The presence of fat hinders the process of decomposition. Therefore, bones are sometimes first treated with steam to remove fat before they are crushed. Steamed bones are more brittle and easy to crush, and at the same time they decompose more readily than the raw bones. Steaming, however, removes a small proportion of nitrogen and, thus, reduces the nitrogen content of the treated product, but increases its phosphoric acid and lime contents. It also increases the citric solubility of calcium phosphate.

TABLE 30. ISI SPECIFICATIONS FOR BONE-MEAL

	Raw bone-meal	Steamed bone-meal
Moisture, per cent by weight, *max.* ..	8.0	7.0
Total nitrogen, per cent by weight, *min.* ..	3.0	..
Total phosphates (as P_2O_5), per cent by weight, *min.*	20.0	22.0
Available phosphates (as P_2O_5), soluble in per cent citric acid, per cent by weight, *min.*	8.0	16.0

Particle size—In the case of raw bone-meal, the material shall pass wholly through IS sieve 240 (aperture 2,399 microns) of which not less than 70 per cent shall pass through IS sieve 80 (aperture 790 microns).

In the case of steamed bone-meal, not less than 90 per cent by weight of the material shall pass through IS sieve 120.

Most of the bone-meal sold in the market consists of crushed, unsteamed raw bones. Its nitrogen content varies from 3.5–4.5 per cent, total phosphoric acid from 18–25 per cent, citric-soluble phosphoric acid from 7–9 per cent, and lime from 28–32 per cent. It has practically no potash. Its C-N ratio varies from 3.5–6.0. Steamed bone-meal contains 1–2 per cent nitrogen and correspondingly greater amounts of phosphoric acid and lime. The Indian

Standards Institution has laid down specifications for raw and steamed bone-meal as shown in Table 30.

Bone-meal is essentially a phosphatic fertilizer. Its effectiveness is increased by the small amount of nitrogen and other essential major and minor plant nutrients present in it. It is a slow-acting manure liberating the plant nutrients in available form more gradually. It is particularly suitable for acid soils or soils rich in sesquioxides, and does better on light, well-drained soils that have good aeration. Though it can be used for all crops it is mainly useful for paddy, fruit trees and other irrigated crops. It is best applied at the time of sowing or planting the crop. The dose varies with the phosphate requirement of the crop.

FISH MANURE

Fish also serve as an important source of manure as they contain both nitrogen and phosphoric acid. Nitrogen is present mainly as protein and phosphoric acid as calcium phosphate; both become readily available on decomposition in the soil. Fish is generally dried before it is sold as manure though occasionally fresh fish is also used for manuring crops wherever locally available. Fish is sometimes mixed with common salt before it is dried. The product so obtained contains varying quantities of sodium chloride. Some fish are rich in oil which is often removed, and the residue (known as fish guano) sold as manure. If the fish contains more than 5 per cent oil, it decomposes more slowly.

Several types of fish are sold as manure. Their manurial value is highly variable. The nitrogen content varies from 4 to over 10 per cent and phosphoric acid from 3–9 per cent. The potash content is very low, round about 1 per cent. Its C-N ratio varies between 4 and 5.

The use of fish as manure is restricted mainly to coastal areas on account of the high cost of transport to inland. It can be applied to all crops and has been found very valuable for rice, *nagli* (*Eleusine coracana*), coconut and many types of vegetables and fruit trees. It is usually powdered before use, though sometimes the whole fish or small pieces are pushed in the soil while transplanting. It is a quick-acting manure and can be used either at planting or as a top-dressing.

GUANO

Guano is the dried excreta of sea birds. It also contains the remains of their dead bodies and of fish they consume. It is a fairly concentrated fertilizer, containing nitrogen and phosphoric acid. The nitrogen content varies from 7–16 per cent and phosphoric acid from 8–12 per cent. Some guanos are very rich in phosphoric acid (20–25 per cent) but poor in nitrogen (4–6 per cent). Most of the nitrogen is present as ammonium salt and, hence, it is immediately available.

Deposits of guano are found on islands or on the mainland along the coasts of North and South Americas and other islands in the Pacific, but none in India. This manure is not available in the country at present.

OTHER MANURES

A number of other materials chiefly by-products of small industries are offered for sale as manure. Most of these are available in small quantities and are locally utilized wherever they are produced.

Dried blood. It is a very useful manure, containing 10–12 per cent nitrogen and 1–2 per cent phosphoric acid. Its potash content is usually less than 1 per cent, and its C-N ratio varies from 3 to 4. Dried blood that is black in colour usually contains less nitrogen than the dark-red variety. It decomposes very easily in the soil and its nitrogen and phosphoric acid soon become available to plants. It can be used at any time during the growth of the crop and is effective on all crops and all types of soils.

Slaughter-house waste. It consists mainly of waste meat, intestines, offal, etc., and has a good manurial value (Table 26). It is practically wasted at present, though some municipalities use it for compost making along with nightsoil and town refuse. If dried and ground it should make a very valuable fertilizer containing 8–10 per cent nitrogen and about 3 per cent phosphoric acid.

Hoof- and horn-meal. This is a by-product of slaughter-houses, and is obtained by grinding the hoofs and horns of animals after drying. It contains 10–15 per cent nitrogen together with small quantities of phosphoric acid (1 per cent) and lime (2.5 per cent). Its nitrogen becomes readily available though not as readily as dried blood.

Wool- and silkworm-wastes. Wool-waste is a slow-acting manure and contains 4–7 per cent nitrogen and 1–5 per cent potash. It has been found to give good results with potatoes and other vegetables.

Silkworm-waste contains nitrogen up to 10 per cent and it decomposes fairly quickly. Both these wastes have local use wherever they are produced.

Tannery refuse. This is a by-product of the leather tanning industry and is sometimes offered for sale as manure. It consists of scrapings of flesh, bits of hide and leather, hair, etc. It forms a very slow-acting manure and is also a poor source of manurial ingredients, containing 0.8–1.2 per cent nitrogen. Though leather shavings contain over 8 per cent nitrogen, they are difficult to decompose and remain as such for a long time in the soil.

Some of the tannery wastes contain lime and other chemicals, such as arsenites, chromates, etc., used in tanning leather, some of which are definitely toxic to plants. Hence, great care must be exercised in the use of this material as manure.

Pressmud. Also known as filter-press cake, this material is a by-product of the sugar industry and contains appreciable quantities of phosphoric acid and lime. Its composition is highly variable. It contains 60–70 per cent moisture, and 20–25 per cent organic matter; of the latter 8–10 per cent is finely divided fibre and 0.2–1.0 per cent sugars. The rest is mineral matter. It is generally dried before use when it contains 1.0–1.5 per cent nitrogen, 4–5 per cent phosphoric acid, 2–7 per cent potash, and 3–5 per cent lime. It is a useful fertilizer material and is also used for reclaiming acid and alkaline soils.

Husks and hulls. These are the by-products of seed-milling, shelling and polishing industries, and are sometimes used as manure. Rice husk is a very poor source of manure and is used more often as a soil amendment than as manure. Its nitrogen content varies from 0.3–0.5 per cent, phosphoric acid from 0.2–0.3 per cent and potash from 0.3–0.5 per cent. Groundnut shells have

TABLE 31. MANURIAL VALUE OF MISCELLANEOUS WASTES

	Cotton waste	Tobacco dust	Tobacco stalks	Sugarcane trash
Nitrogen ..	1.0–1.5	1.10	1.12	0.3–0.4
Phosphoric acid (P_2O_5)	0.4–0.8	0.31	0.84	0.1–0.2
Potash (K_2O) ..	1.6–2.9	0.93	0.80	0.4–0.7

a better manurial value, its nitrogen varying from 1.6–1.8 per cent, phosphoric acid from 0.3–0.5 per cent and potash from 1.1–1.7 per cent.

Miscellaneous wastes. The manurial value of some of the other wastes, sometimes used as manure, is shown in Table 31. They are more suitable for compost making than as straight manures.

NIGHTSOIL AND URINE

The quantity and composition of human excreta vary considerably. In villages they depend upon the number of people, their social custom and dietary habits, and the facilities available, if any, for collecting the waste products. In towns and cities the quantity and quality are affected, in addition to the factors mentioned above, by the system of disposal adopted by the municipality, industrial wastes, if any, etc. An idea of the quantity of human faeces and urine excreted and of the manurial ingredients contained in them can be had from the data presented below.

	Weight in g per head per day	
	Faeces	Urine
Quantity, fresh	133.00	1,200.00
Quantity, dried	30.30	64.00
Nitrogen	2.10	12.10
Phosphoric acid (P_2O_5) ..	1.54	1.80
Potash (K_2O)	0.73	2.22

Urine is more important of the two, as it contributes a greater amount of manurial ingredients and at the same time contains them in a soluble and hence readily available form.

In villages there is considerable wastage of both nightsoil and urine. The nightsoil is left exposed to the direct action of sun and micro-organisms. Ammonia and other gases formed during exposure are lost by volatilization. Some of the animals, especially pigs, eat the solid portion of the excreta. Inefficient collection methods also add to this wastage.

The best way of conserving nightsoil is to collect the material carefully and compost it by the Bangalore Method. In villages Wardha type of latrines should be provided in fields. Attention should also be paid to the efficient collection of urine for manurial purposes. The Punjab Agricultural Department has investigated the methods of conservation of urine and designed a utility urinal, the Agrosan urinal, which is recommended for general use in urban areas. In Uttar Pradesh, Maharashtra, Gujarat, Delhi and other places, with certain improvements, it has been found to be very suitable for urban centres.

The simplest method of preserving human urine is by the pit method and this is quite suitable for small towns and villages. A pit 0.9 m × 0.9 m × 0.9 m is dug at a suitable place and filled with alternate layers of dry refuse and earth respectively, till the last layer remains 5 cm below ground level. This is then covered with 2.5 cm layer of dry earth. When the urinal is used the urine will soak into the absorbent material. If properly used there will neither be any foul smell nor development of unhygienic conditions. When the soaking material is saturated with urine, the upper layer of earth will appear moist and there will be a smell of ammonia. Then the pit should be covered with an additional layer of loose earth. After the closure of the first pit similar operations should be continued in a second one. The manure of the first pit will be ready for application to fields in about two months after closure. If steps are taken to conserve the urine voided by the population, more than 1.5 million tonnes of nitrogen, an equal quantity of potash and three lakh tonnes of phosphoric acid can be conserved in a year.

CONSTRUCTION AND USE OF LATRINES

Wardha type. The Wardha type latrine consists of two separate parts, the trench and the super-structure.

For every unit structure there are two trenches of similar dimensions for use in relay. When one is in use the other may be excavated after the manure is ripe. The internal dimensions of the trenches (after brick-lining) for six seats are 6 m length × 60 cm breadth × 120 cm depth. Each is 90 cm underground and 30 cm above ground. The trenches should be constructed as described below:

A trench 6.45 m long, 1.05 m broad and 0.9 m deep is dug. Its entire bottom is laid with 11.25 cm bricks on edge with lime and mortar. Over this, a 22.5 cm brick wall is constructed in lime and mortar all around with a 7.5 cm offset on all sides. The wall should be built 30.45 cm above ground (0.9 m underground). 22.5 cm cross walls at a distance of a meter (centre to centre) are also constructed. A similar trench is constructed a few meters apart from the first. These trenches should be constructed together with a central common 30–45 cm thick wall. *Murrum* is spread and properly dressed to a width of 10 cm all round with a slope of 1 in 2.

The super-structure consists of fly-proof platform on top of the trench and shiftable enclosure with partition walls, doors and roof constructed in two units, each 3 m in length.

Two 11.25 cm diameter teak ballies, each 6.08 m long (divided into two pieces of 3.04 m length) are placed along the length of the pit at 71.5 cm in centre for supporting the wooden platform and squatting seat. The platform can be made from the side cuts of the teak logs. The joints of the teak planks should be air-tight. A 22.5 cm × 60 cm opening should be provided for each seat. Over the opening is fixed a fly-tight cover, 30 cm × 60 cm, with hinges and handle for lifting. This rests on 2.5 cm wooden groove made in a plank 3.75 cm thick. The platform may be constructed in two parts so that it can be easily lifted and fixed over the trench.

The super-structure consisting of wooden batons, bamboos and bamboo mats can be a light and closed type constructed of four wooden ballies with small wooden supports for resting it on the ground. Each latrine seat must be closed on all sides, the front being used as the door. A suitable lean-to-roof must also be provided. Bamboos and matting should be coated with creosote or tar to protect against weather and damage from white ants. A live hedge of 1.2–1.5 m height may be grown around the latrines.

The estimated cost of this structure, inclusive of trenches, is about Rs 750 per unit of six seats for 60 persons at the prevailing (1960) cost of materials.

Before the latrines are brought into operation, a 7.5 cm layer of refuse (garbage, grasses, leaves, spoilt straw, weeds, trash, etc.) should be spread at the bottom of the trench and a stock of refuge or dry earth be left near each privy for daily use. The trench should be put out of use after the materials have risen to a height within 15 cm from the top; the super-structure is then shifted to the other trench.

One trench of the above size will be sufficient for 60–80 persons for nearly three months. Separate units should be allotted for men and women.

Water seal type. This is designed for the flush-out of faeces and urine into compost pits closely.

The design provides for a brick work (stones or other materials retaining wall). The squatting plate for the closet is 6.5 cm × 6.5 cm in RCC with foot-rests. The length of the pan or closet is 42.5 cm with 30 cm width at its back and a P–trap of 7.5 cm diameter is used. A 7.5 cm diameter pipe of stoneware leading to the pit is laid to a gradient of 1 in 20 for easy and free flow. The nightsoil composting is done in two pits, each 1.2 m × 0.9 m × 0.9 m; these are used alternately. The pits should be located above the ground water-level. The pit should be lined with dry packing of bricks or rough stones, if the soil met with is loose and covered with fly-tight G.I. cover over C.W. joints, 7.5 cm × 7.5 cm, laid lengthwise and breadthwise with a hinged door opening, 45 cm × 45 cm, for adding refuse. This opening should also be provided with tight fly-proof cover with a handle and bolt.

The water seal closet should be enclosed by a temporary structure of bamboo posts with bamboo matting and a door at front for entry. If the temporary enclosure has to be enlarged to an area greater than 45 cm, the peripheral portion between the retaining wall and the enclosure should be protected from damage by white ants.

The approximate cost of the latrine will be Rs 100 to 125, including a brick enclosure wall.

Before the latrine is brought into operation a 7.5-cm-layer of refuse (garbage, grasses, leaves, spoilt straw, weeds, trash, etc.) is spread at the bottom of the pit and a stock of refuse and some earth left near the pit for daily use.

During the operation one of the compost pits is connected to the flush-out system, while the other is kept closed. The village sweeper or scavenger is expected to look after the proper maintenance of the flush-out and also spreading rubbish and earth over the collected faeces in the pit daily or once in two days to avoid fly nuisance and ensure proper decomposition of the waste materials in the pit. By the daily addition of rubbish and small quantity of earth to the pit at the rate of one basketful to cover the faeces, including washed liquid from the flush-out collected therein, the entire pit can be filled during the course of five to six months. Thus, each pit will yield ultimately ripe compost of not less than half a ton for a household of five members. When the first pit is almost full the entire material is raked up and covered with 5-cm to 7.5-cm-layer of earth and the pit closed with concrete lid. The material is allowed to undergo further decomposition for a period of one month and then removed for use as manure. After the first pit is filled in this manner, the second pit is connected to the flush-out and the operation is repeated as in the case of the first one. By the time the second pit gets filled up the first pit is ready for further use.

NIGHTSOIL COMPOST

Composting of nightsoil and other waste materials may be carried out under aerobic and anaerobic conditions. The preparation of nightsoil and other composts is effected in a much shorter period under aerobic conditions without production of objectionable odour than when the materials are allowed to decompose anaerobically. In the utilization of human and other organic wastes for composting due attention should be paid to their proper handling and processing to avoid incidence of faecal-borne diseases.

Preparation of compost. In the various methods followed, provision of optimum conditions should be provided for the activity of the micro-organisms responsible for the breakdown of the coarse plant and animal residues. The Indore Method, mainly aerobic and involving two or three turnings of materials, is being adopted in India and other countries with suitable modifications for preparation of quality compost from urban and other wastes, including nightsoil. The manufacture of compost on a factory scale by mechanizing the process is also carried out in western countries and Japan. Beccari's mechanized process is the most important one. Here composting is done initially under anaerobic conditions, followed by a final aerobic stage in an enclosed cell to minimise the nuisance due to foul smell produced during the anaerobic decomposition of the waste materials. Its modified version with facilities for better aeration and efficient circulation of drainage liquors or gases is at present used in some countries in Europe. But a mechanized process involving heavy expenditure may not prove economical under the Indian conditions, except perhaps in big cities and towns.

Essentials for good composting. 1. The available waste materials used should be well mixed in suitable proportions of hard, soft, dry and green materials to form a good physical texture for maintaining continued optimum conditions of moisture and aeration. A good compost is prepared from a heterogeneous mass of vegetable and animal residues rather than from a single material.

2. The presence of an optimum quantity of water is essential for the activity of micro-organisms which bring about the decay of the raw materials. The moisture content of the compost mass should be kept at 45–50 per cent. This is possible if the proportion of nightsoil of right consistency and rubbish is 1:1 by weight or 1:3 by volume. Sullage or sewage water may also be used for wetting the rubbish to the required level, wherever possible. As rough guide to the moisture content, the material when squeezed in the hand should fail to form a lump or in other words should form a ball which will slowly expand like a sponge when the pressure is released.

3. Proper aeration of the material, especially during the initial stages of composting, is as essential as the proper moisture content. The decay of organic matter in a compost pile is mainly due to aerobic and anaerobic bacteria. Decomposition brought about by the former is much quicker and has certain advantages over the latter especially during the initial stages. Anaerobic decomposition sometimes results in a product which may be partially decomposed and foul smelling. In a properly aerated compost pile, an initial high temperature of about 60°–65° C is obtained. It destroys most of the weed seeds and harmful pathogenic micro-organisms in the compost material.

4. To bring about immediate and vigorous decomposition it is essential to inoculate the raw materials with a starter. This will provide enough organisms along with the nutrients required by them. Cowdung, urine, earth, nightsoil, sewage sludge and fermented farmyard manure are some of the commonly available starters. Pig-dung has been found to be an efficient starter which gives a final product rich in nitrogen. Many patented bacterial compost-starter cultures are sold in the market, but these have not become popular in our country since the commonly available cattle-dung, nightsoil and other starters mentioned above are equally efficient.

The amount of starter to be added depends on the nitrogen content of the material and the kind of starter used. As a general rule, the nitrogen content of the prepared piles should be about 1.25 per cent of the dry matter. The nutrients for the bacteria may also be supplied in the form of fertilizers, urine, ash, bonemeal, etc. Their addition accelerates decomposition and produces a better product.

5. Acidity in a compost pile may be corrected by addition of the required quantities of agricultural lime or wood-ash. Soil, when added to the raw material while composting, serves as a buffer against acidity.

6. When all the aforesaid factors are favourable, bacterial action will be vigorous and the temperature of the compost mass will rise up to 60°C within three or four days from start. In practice, a rise in temperature may be taken as an indication of proper progress of decay of the material.

Apart from these factors attention should also be paid to the following points in the manufacture of compost with high manurial value

The salvaging of rags, tin cans, glass pieces, stone, etc., which are of no use for composting is necessary for the production of quality compost.

The control of flies in compost mixtures of refuse and nightsoil can be achieved by covering the heaps or pits with a 23 cm layer of dry refuse, followed by a 5-cm layer of loose earth. Fly-breeding in compost heaps and pits can also be arrested by covering them tightly with tarred cloth, taking care to seal the cloth tightly around the edges of the pits or heaps. The same tarred cloth can be used a number of times without involving much expense.

Preparation of nightsoil compost. Of the various methods advocated for preparation of nightsoil compost, the Bangalore Method is the most economical, simple and sanitary. It is already being followed in several states in our country.

The site selected for the compost depot should be situated about a km away from the outskirts of the town on the windward side. Composting, according to Bangalore Method, is preferably carried out in trenches with longer sides, parallel and shorter sides in a line. An interspace of 1.5 to 2.1 m between successive trenches or heaps should be left for easy handling and watering of the rubbish. The size of the trenches should be regulated according to the population and quantity of refuse as follows:

Population (in 1,000)	Length (m)	Breadth (m)	Depth (m)
Below 5 ..	4.5	1.5	0.75–0.9
5–10 ..	6.0	1.8	0.9
10–20 ..	7.6	1.8	0.9
20–50 ..	9.1	2.1	0.9
Above 50 ..	10.6	2.4	1.05

A layer of rubbish free from stones and glass pieces is spread uniformly at the bottom of the trench with long-handled rakes to a thickness of 22.5 cm and covered with a calculated quantity of

nightsoil corresponding to 7.5 cm thickness and equivalent to the weight of the rubbish used (The actual number of cartloads of dry refuse and nightsoil required for each layer may be worked out according to dimensions of the trenches or heaps). Succeeding layers of dry refuse and nightsoil are similarly added till the heap rises 45 cm above the ground level. The top layer at the end of each day should be about 22.5 cm thick refuse. This may be covered with a 1.25 cm to 2.5 cm layer of earth to suppress effectively the bad odour, conserve the moisture and nitrogen in the compost mass and for checking the fly nuisance. Where nightsoil cannot be had in sufficient quantity for treating the available rubbish, the proportion of two parts by weight of rubbish to one part of nightsoil may be adopted instead of equal weights of each.

Within three or four days after filling the trench, high temperature (over 60°C) is developed in the compost mass and as it persists for two to three weeks, pathogenic organisms and weed seeds are destroyed to a great extent.

The surface of the heap may be made dome-shaped and covered with a 2.5-cm to 5.0-cm layer of earth five or six days after laying the heap. After a period of five to six months the material within the trench is found to have thoroughly decomposed. The final product, if properly prepared, will be of high manurial value and superior to farmyard manure.

In places receiving heavy rainfall or where water-table is high, the compost heaps may be prepared above ground instead of in trenches. All vegetation should be removed as also the top 22.5 cm soil to make a shallow pit. The soil removed can be used later for plastering the pile or for interlaying when the pile is built. The pile should be 1.2–1.5 m high, 1.8 m wide and

3.6 m long and should have sloping sides. The length of the pile may be increased to suit requirements, keeping the width and height the same.

The decomposition will be complete within five to six months. The finished product will be dark-brown in colour, crumbly in texture and has the so-called characteristic woody odour without any unpleasantness about it. The compost prepared may be applied to soils in the same way and in equivalent doses as cattle manure. It can be supplemented by nitrogenous, phosphoric and potassic fertilizers, depending on the crops to be manured and fertility status of the soil.

CHAPTER V

FERTILIZERS

GENERAL

Classification. Nitrogen, phosphorus and potassium are important elements, and are required in large quantities by crops. These are most commonly deficient in soils. Therefore, concentrated fertilizers of each of these nutrients and mixtures of single nutrient fertilizers are manufactured and applied to the soil to raise the fertility of the land. The modern terminology based upon composition is N, NP, NK, PK and NPK fertilizers, where N stands for nitrogen, P for phosphorus and K for potassium. Fertilizers which contain only one plant nutrient are termed 'straight fertilizers' as distinguished from 'compound fertilizers' which have two or more plant nutrients. Most of the fertilizers are applied in the form of solids', but some are applied as 'solutions'. Of the latter class are anhydrous ammonia and ammonia solution, especially those containing ammonium nitrate or urea. These are important sources of nitrogen for solid, mixed fertilizers.

General characteristics. Fertilizers influence the reaction of the soil. Accordingly they are classified as: (*a*) acidic or acid forming, (*b*) neutral, and (*c*) basic or alkaline fertilizers. For instance, ammonium sulphate is an acidic fertilizer. When constantly applied to neutral soil it will show a tendency to turn the soil into an acidic one. Ammonium nitrate is a neutral fertilizer. It neither turns the soil acidic nor basic. Sodium nitrate is a basic fertilizer and its continuous use on some of the soils turns them alkaline. It is only by the continuous use extending over long periods of time that such effects are manifested in the soil. It is, therefore, common to recommend the use of appropriate fertilizers which will suit the soil and bring its reaction as close to neutral as possible, because all elements essential for crop growth are mostly available at neutral reaction (pH 7.0). Besides the reaction of the fertilizer there are other more potent factors which modify their action. In light soil where irrigation facilities exist or there is adequate rainfall the use of sodium nitrate may not produce alkalinity. But sodium will accumulate rapidly in the soil if the soil is heavy and the rate of infiltration is low.

To be effective the fertilizer should not liquefy, cake or become sticky. In order to flow easily through the drill, the fertilizer should be dry, its particles spherical in shape and uniform in size and should not stick to each other. The granulation of fertilizers is now common for straight, as well as, mixed fertilizers. The fertilizers should not be so acidic as to destroy the bags.

Some fertilizers, such as ammonium nitrate, are very hygroscopic in nature and rapidly absorb moisture, particularly during the monsoon season. Either their hygroscopicity is reduced by addition of a 'conditioner' or they are stored in moisture-proof bags. Alkathene-lined bags have become popular for this purpose. Lime is added as a conditioner to the Nangal-produced ammonium nitrate in order to reduce its moisture-absorbing capacity to the minimum.

Grades and ratios. The grade of the fertilizer denotes the percentage of plant nutrient in the material. This term is used for both compound and mixed fertilizer materials. The plant nutrients are in the following order: total nitrogen (N), available phosphorus pentoxide (P_2O_5) and water-soluble potash (K_2O). A fertilizer of the grading 10:10:5 consists of 10 parts of nitrogen, 10 parts of phosphoric acid and 5 parts of potash. Thus, it contains 11.3 kg of plant food per 45.3 kg gross weight of the fertilizer. In contrast to this ammonium sulphate contains 9.2 kg nitrogen as plant food in 45.3 kg fertilizer bag. The ratio of the grade 10:10:5 is 2:2:1. This ratio indicates the proportion in which N:P:K are in the fertilizer material.

In India, most of the fertilizers are used as straight materials. But in the States of Madras, Mysore and Andhra Pradesh several grades are in vogue and more are being introduced by the fertilizer-mixing companies. In southern India the soils are generally shallow and lack nitrogen, phosphorus and potash. Therefore, several grades for rice, potato, tapioca, sugarcane and groundnut have become popular.

Fertilizer materials. The properties of straight fertilizers and compound fertilizers, their production, composition, suitability to soil conditions, criteria of selection for various crops, etc., are described here.

NITROGEN FERTILIZERS

Classification and importance. The nitrogenous fertilizers are broadly classified in Table 32.

Of the nitrate fertilizers the most common in use is sodium nitrate or calcium nitrate of commerce. Calcium nitrate is partly applied by farmers in the U.K. and the European continent. But due to the low level of nitrogen its use is diminishing at a fast rate in favour of high analysis fertilizers. At one time potassium nitrate was in general use. Its consumption was much reduced during the World War I. Since then it has not been much in demand due to high price of plant food in comparison to other materials.

TABLE 32. CLASSIFICATION OF NITROGENOUS FERTILIZERS

Source of nitrate	Name of material	Percentage of nitrogen	Equivalent	
			Acidity	Basicity
Nitrate	Sodium nitrate	16.0	..	29
	Calcium nitrate	15.0	..	21
	Potassium nitrate	13.0	..	29
	Nitrate of soda-potash	15.0	..	26
Ammonium	Ammonium sulphate	20.5	110	..
	Anhydrous ammonia	82.2	148	..
	Ammonium chloride	25.0	128	..
	Monoammonium phosphate	11.0	55	..
	Diammonium phosphate	21.0	77	..
Nitrate and ammonium	Ammonium sulphate-nitrate	26.0	93	..
	Ammonium nitrate	33.5	60	..
	Calcium ammonium nitrate	20.5	..	..
Amide	Calcium cyanamide	22.0	..	63
	Urea	46.6	80	..

Ammonium sulphate is the most widely used fertilizer. It has good physical and chemical properties. Its manufacture and consumption are still on the increase. Anhydrous ammonia was first marketed in the U.S.A., and its consumption is rapidly expanding due to the low price of plant food in it. Its production and consumption has not as yet expanded in other countries but may do so in the near future. Ammonium chloride is being used on an increasing scale in Japan where it is a by-product of the soda-ash industry. Its production will soon be taken up in this country at Banaras. Mono-ammonium phosphate and diammonium phosphate are high analysis fertilizers which are principally used for application to legumes or used on soils highly deficient in phosphate.

Ammonium sulphate-nitrate is a compound fertilizer consisting of ammonium sulphate and ammonium nitrate. It contains 20 per cent of ammoniacal and 6 per cent of nitrate-nitrogen. It is a fairly stabble fertilizer. Its manufacture at the Sindhri fertilizer plant was taken up to economize in the use of sulphur derived from gypsum. Ammonium nitrate contains half of its nitrogen in ammoniacal form and half in nitrate form. It is very hygroscopic in nature. Its manufacture is being planned at Nangal and at Rourkela fertilizer plants. But it will be conditioned with lime to bring down the nitrogen to 20.5 per cent in order to reduce its hygroscopicity and the hazards of explosion. This product will then be called calcium ammonium nitrate. Some quantities of this fertilizer are being imported from Germany to meet the growing demand for it from the farmers.

Urea is another high analysis fertilizer which will be manufactured in this country. Besides containing about 45–46 per cent of nitrogen, the highest in any solid fertilizer, it does not require sulphur which is in short supply in this country, for its manufacture. It is less hygroscopic in nature than ammonium nitrate. Its manufacture at the Sindhri factory has been taken up on a small scale but its production will rapidly increase when factories start working at Neyveli, Rourkela, Bombay and other places. The manufacture of calcium cyanamide was taken up in 1910 in the U.S.A., but its manufacture has not expanded very much as the fertilizer is not in much demand. There is no proposal to manufacture this fertilizer in this country.

Process of manufacture

(*a*) *Sodium nitrate*: It is one of the naturally occuring chemical source of nitrogen. The deposits found in Chile were first discovered by Theddens Haenke in 1809. The mining operations were started in 1813. These deposits cover an area of 1,165 km^2 at an elevation of 1,219–2,286 m above sea-level. The upper layer of the deposit is called *costra* and the lower layer is termed *congelo*. Beneath the *congelo* layer is the *caliche*, the immature deposits of sodium nitrate. The *congelo* has a high

percentage of sodium chloride. The layer of *costra* and *congelo* vary from 0.9 to 3 m. The *caliche* consists of 8–25 per cent of sodium nitrate, 2–12 per cent of sodium chloride and 2–3 per cent of sodium sulphate, the rest being sand, gravel and clay. The sodium nitrate is recovered either by the Shanks process or Guggenheim process. Now only 10 per cent of the nitrate is produced by the former process and the rest 90 per cent by the latter process.

The material for Shank process consists of *caliche*, without prior stripping of *costra* and *congelo*. This material is sorted out and transported to the refinery. It contains at least 13 per cent of sodium nitrate. After powdering the raw material is charged into tanks of 50.8–91.44 tonnes capacity. The solution in tanks is boiled for 12–15 hours with nitrate liquor from the second tank. This solution is boiled in three-step process. The boiled liquor from the first tank is fairly viscous, is drained and is then air-dried for three months. To this tank a weak solution of the brine from the second tank is added for boiling and from the third tank into the second tank. Thus, the less-concentrated brine is used for extraction of richer ones. After the last extraction the spent solids are discarded. This extracts 65 per cent nitrate only. The extracted and air-dried material has 1–2 per cent of moisture and 96 per cent of sodium nitrate as crystals.

Guggenheim's process developed in 1926 is more mechanized than the Shanks' process. More efficient use is made of the heat in the process of boiling the brine. The *caliche* ore containing about 8 per cent of sodium nitrate is powdered and screened. The screened material is leached in a filter plant. The remainder of the material is crushed and charged into 7,620–12,192 tonnes capacity tanks. Into these tanks the mother liquor from the crystallizing plants is charged. The temperature is raised to 40°C. The saturated liquor is withdrawn from the head tanks and cooled in a crystallizing plant where it is refrigerated. The thickened slurry is centrifuged. The crystals are heated in a furnace at 340°C and the viscous liquor is sprayed into pellets. The pellets are passed on to a cooler and the sodium nitrate formed is bagged. Some of the mother liquor from the centrifuge is fed into tail leach tank and from there the concentrated liquor is allowed to overflow into the head leach tank. The process is capable of extracting 75 per cent of the sodium nitrate from the raw material. The leached and washed ore is finally discarded. The complete extraction from a given charge of the ore takes about 40 hours. The pelleted material contains 1 per cent moisture and 99 per cent sodium nitrate.

In this process the other salts recovered are sodium chloride, double salt of sodium and magnesium, sodium potassium nitrate, borates, iodates, sulphates and perchlorates of potassium, magnesium and calcium. These by-products very appreciably reduce the cost of processing the raw material into sodium nitrate.

(*b*) *Calcium nitrate*: Several attempts, particularly in Norway, have been made to produce calcium nitrate by fixing atmospheric nitrogen and converting it into nitric acid by electrolytic process. The nitric acid is neutralized with limestone to obtain calcium nitrate. The production of nitric acid by the electrolytic process has not succeeded to any large extent. Now the ammonia produced by direct synthetic process is transformed in the presence of catalyst into nitric acid. The reactions are given on the next page.

$$4NH_3 + 5O_2 - 4NO + CH_2O + \text{heat}$$
$$2NO + O_2 - 2NO_2 + \text{heat}$$
$$3NO_2 + H_2O - 2HNO_3 + NO + \text{heat}$$

The anhydrous ammonia is first passed through evaporator and then led into mixer-filter where air is let in. This mixture of ammonia and air is passed on to a converter containing platinum gauze and maintained at 280-300 °C. The reaction in the presence of catalyst takes place at 900 °C. The hot gases are cooled and then passed through an oxidation tower, where most of the gas is converted into nitric oxide. The issuing gas is obsorbed in water in the absorption tower and nitric acid drawn off to storage.

This nitric acid is brought in contact with the limestone to neutralize it as shown below:

$$CaCO_3 + 2HNO_3 - Ca(NO_3)_2 + CO_2 + H_2O + \text{heat}$$

The strength of the nitric acid is 50 per cent. The acid is neutralized by feeding with crushed limestone. The solution formed contains about 40 per cent of calcium nitrate. This is concentrated in a series of vacuum evaporators to about 87 per cent. To raise the nitrogen content of the final product to 15.5 per cent, 5 per cent of ammonium nitrate is added to the 87 per cent strong solution. The solution is then sprayed in 30 m pelleter through a centrifugal type of nozzle. The pellets are then dehydrated and bagged.

Ammonia fertilizers

(*a*) *Anhydrous ammonia*: There are two major processes by which ammonia gas is obtained for production of anhydrous ammonia, ammonia solutions or salts of ammonia. These are destructive distillation of coal and Claude–Haber ammonia synthesis.

The former process consists of heating cooking coal, which contains 1–2 per cent of nitrogen, in ovens at 822°C in the absence of air. The volatile substances containing tar, ammonia and light oils are led to the tar separator where these are cooled by a spray of dilute ammonia water. This solution then flows to a decanter where tar is separated out. The ammonia collected there is taken either to primary cooler or allowed to flow to the decanter again for use as ammonia spray. The ammonia gas, still containing some tar, is cooled in the primary cooler where tar is condensed and transferred to the tar separator. This is then fed to the saturator after preheating. Here light oils and gases other than ammonia are separated out. The water from the ammonia is removed by condensation. This purified ammonia gas is transported as anhydrous ammonia under pressure in specially designed transport cars.

The Claude-Haber ammonia synthesis process consists of directly combining nitrogen and hydrogen to form ammonia. The essentials of this process were developed by Haber in Germany in 1910. Claude, in France, improved upon its manufacturing process. The synthesis of nitrogen and hydrogen is carried out in the presence of catalysts, such as osmium, iron and platinum at temperatures ranging from 400°-500°C at pressure range of 200–1,000 atmosphere. The catalyst surface is nitrited, with subsequent reduction of nitrite by hydrogen, to form ammonia.

The hydrogen gas is either prepared by water gas process or a combination of water and producer gas. In the former process the stem reacts with incandescent carbon. The reaction is as follows:

$$C + 2H_2O - CO_2 + 2H_2$$

This process requires frequent reheating of the coke bed.

In the new process involving water and producer gas the carbon monoxide evolved by the process of water gas reacts with water according to the reaction given below, to produce hydrogen:

$$CO + H_2O - CO_2 + H_2$$

This step contributes substantially towards formation of hydrogen and removes easily CO_2 instead of dealing with troublesome carbon monoxide

Another method of preparing hydrogen is the reforming of natural gas, principally methane, with steam over a nickel catalyst. The reactions are shown below:

$$CH_4 + 2H_2O - CO_2 + 4H_2$$
$$CH_4 + H_2O - CO + 3H_2$$

The gas thus produced has an approximate composition (in per cent) of: hydrogen 60, nitrogen 20, CO_2 16 and carbon monoxide 4. This process is likely to be adopted for utilizing waste flue gases for production of synthetic nitrogenous fertilizers in India. This is already in use in the U.S.A.

The ammonia is obtained by passing air into the reactor with the hydrogen. As this involves use of hydrogen the cost of nitrogen for synthesis is high. The second method employed is to use the producer gas resulting from reheating of the coke beds for combining with hydrogen for synthesis. Ammonia thus synthesized by reaction of nitrogen and hydrogen is either stocked as anhydrous ammonia or used for the manufacture of ammonium sulphate and other ammonium salts.

(*b*) *Ammonium sulphate*: This involves the use of ammonia and sulphuric acid. The suphuric acid is either produced by the chamber process or by the contact process. The sulphur or sulphur ores or gypsum are burnt to evolve sulphur dioxide. By passing sulphur dioxide over a catalyst sulphur trioxide is produced. This is absorbed in water. In the chamber process nitrogen oxides are used as catalysts. In the contact process vanadium oxide is employed as catalyst. The reactions involved are as given below:

$$S + O_2 - SO_2 + \text{heat}$$
$$2SO_2 + O_2 - 2SO_3 + \text{heat}$$
$$SO_3 + H_2O - H_2SO_4 + \text{heat}$$

The sulphur is burnt in purified air. At a temperature of 550°C, in the presence of catalyst, SO_2 combines with oxygen to form sulphur trioxide. This is cooled and sulphur trioxide is absorbed in 98 per cent sulphuric acid. Thus, in the contact process 312 kg of sulphur is converted into 453.5 kg of 100 per cent sulphuric acid.

The anhydrous ammonia is evaporated to ammonia or ammonia produced by destructive distillation of coal is drawn off, is diluted with air and brought into contact with sulphuric acid. The following reaction takes place:

$$2NH_3 + H_2SO_4 - (NH_4)_2SO_4$$

The ammonium sulphate solution after cooling and crystallization is supplied to centrifuges where ammonium sulphate crystals are separated from the liquor and passed on to the dryer. The fertilizer, sulphate of ammonia, as crystalline product, is bagged. The percentage of nitrogen in ammonium sulphate varies according to the process employed. The by-product contains about 20.5 per cent of nitrogen, while that produced from synthetic ammonia contains 21 per cent of nitrogen.

(*c*) *Ammonium chloride*: This fertilizer is manufactured by the ammonia-soda process. The products obtained are soda and fertilizer grade ammonium chloride. The reaction is as follows:

$$NaCl + CO_2 + NH_3 + H_2O - NaH\ CO_3 + NH_4Cl$$

The sodium bicarbonate is precipitated. The solution of ammonium chloride is concentrated, cooled and crystallized. The crystals are passed through a cooling and dehydrating plant and the product is bagged. In the process, the chemical reaction is made up to 75 per cent maximum due to equilibrium of the reactions, so that sodium chloride is recovered unreacted which amounts to 25 per cent. The fertilizer contains 25 per cent nitrogen. Its production has been rapidly increasing since 1950 in Japan. In 1957 the total quantity produced exceeded the planned quantum, 296,672 tonnes. In India it is planned to manufacture ammonium chloride in the private sector also.

(*d*) *Ammonium phosphate*: The monoammonium and diammonium phosphate fertilizers are principally manufactured as phosphatic fertilizers. Both these are produced by the neutralization of phosphoric acid by ammonia. The reaction for the preparation of this fertilizer is as follows:

$$NH_3 + H_3PO_4 - NH_4\ H_2PO_4$$

Monoammonium phosphate contains 11 per rent of N and 48 per cent of P_2O_5. It is completely soluble in water and is now extensively used in the U.S.A. and European countries as a compound fertilizer.

If the slurry produced by the neutralization of ammonia and phosphoric acid be kept at pH 5.8–6.0 then the resulting reaction is as follows:

$$2NH_3 + H_3PO_4 \text{ — } (NH_4)_2\ HPO_4$$

The fertilizer grade diammonium phosphate contains 21 per cent of nitrogen and 53 per cent of P_2O_5. It has a very high content of plant food per bag and has good storage properties. It is proposed to manufacture 85,344 tonnes of this fertilizer at Rourkela fertilizer factory.

Ammonia-nitrate fertilizers

(*a*) *Ammonium sulphate-nitrate*: This fertilizer is manufactured by neutralizing a mixture of sulphuric acid (77 per cent H_2SO_4) and nitric acid (50 per cent HNO_3) with anhydrous ammonia. The mixture contains 3 per cent of water at a temperature of 150° C. About a tonne of ferrous sulphate ($FeSO_4$, $7H_2O$) is added for every 26 tonnes of nitrogen to prevent the product from caking in the saturator. The product is solidified at about 100° C. Thereafter it is granulated, dried and bagged. The product contains 26.6 per cent of nitrogen.

(*b*) *Ammonium nitrate*: For the preparation of ammonium nitrate the nitric acid is neutralized with ammonia. The reaction is as follows:

$$HNO_3 + NH_3 \text{ — } NH_4\ NO_3 + \text{heat}$$

The nitric acid has the strength varying from 58–65 per cent. The heat of reaction is sufficient to remove the water during neutralization. The solution contains 80 per cent of ammonium nitrate. From there it is sprayed into pelleting tower to form ammonium nitrate pellets which are cooled and dried simultaneously before the product is bagged. Usually the pellets are coated with petroleum-rosin-paraffin mixture and 3–5 per cent of anti-caking agent. This contains 33 per cent of nitrogen. This process will be employed for the manufacture of calcium ammonium nitrate in the Nangal factory, where the ammonium nitrate will be mixed with limestone to contain 20.6 per cent of nitrogen. This product will be less hygroscopic than the original product and will be free from hazards of fire.

Amide fertilizers

(*a*) *Calcium cyanamide*: The process for the commercial manufacture of cyanamide was perfected in 1900 and the production was taken up soon after in Europe and in 1910 in the U.S.A. The chemical reactions involved are detailed below:

$$CaCO_3 \text{ — } CaO + CO_2$$

$$CaO + C_3 \text{ — } CaC_2 + CO_2$$

$$CaC_2 + N_2 \text{ — } CaCN_2 + C$$

The raw material required for the manufacture are limestone and coal. The limestone is fired at 1,300°C to produce lime. The lime then reacts with coke in continuous type electric furnaces at 2,200°C to produce fused calcium carbide which is withdrawn and solidified. Highly purified nitrogen is obtained by liquefaction of air; after CO_2 has been removed by passing through caustic soda and fractional distillation, the calcium carbide is made to react with nitrogen in the presence of calcium fluoride in batteries of cylindrical batch-type ovens under slight pressure at a temperature of 1,000°C. The product is dehydrated, granulated or pulverized.

(*b*) *Urea*: The manufacture of urea is being taken up on increasing scale in various countries. It is manufactured by reacting carbon dioxide and anhydrous ammonia under very high pressure and temperarture. The reaction is as follows:

$$4NH_3 + 2CO_2 \text{ — } NH_2\ COONH_4\ NH_2\ CONH_2 + H_2O$$

To increase the conversion rate, excess of ammonia is used. The unreacted ammonia and carbon dioxide are recycled. The urea solution is centrifuged and after mixing with conditioning agent is passed through a mixer dryer to be bagged. The manufacture of urea has already been taken up in a plant capacity of 71.12 tonnes per day at the Sindhri factory. Another 66,040 tonnes of urea will be manufactured at Neyveli in South India. Further manufacture is envisaged at Bombay, Cambay and other sites.

(*c*) *Suitability to different soil types*:

1. SODIUM NITRATE: Due to the presence of sodium it is a basic fertilizer and produces alkalinity in the soil. In light soils, which have good drainage, sodium does not accumulate. But in soils of poor drainage sodium tends to accumulate provided the soils are of neutral or alkaline reaction. The fertilizer should not ordinarily be used on such soils as far as possible. But for acid

soils, which have a low content of lime, addition of sodium corrects the acidic reaction and conduces to greater availability of phosphorus and calcium to the crops. That is why sodium nitrate is very popular in countries which have acidic soils.

In India most of the acidic soils are met with in high rainfall areas of Assam, West Bengal, Bihar, Orissa, Mysore, Kerala and Maharashtra. Paddy is the chief crop grown in these areas by the farmers. Since nitrate in this fertilizer is readily dissolved in water and remains in solution it leaches out of soil. Accordingly its application to soils in wet areas is not generally recommended. It is only for light lands, where drainage is unimpeded, that its use in neutral or slightly acidic soils is suggested. In wet areas, where soils are of acidic nature, it can be applied in the pre- or post-monsoon seasons when chances of leaching out of the nitrate are the least.

2. CALCIUM NITRATE: Excepting very small lots obtained from abroad not much of the calcium nitrate is available for use in India. It is again suitable for acidic soils more pre-eminently than for calcareous or saline-alkaline lands. It should not be generally used under very wet-land conditions as nitrate is likely to leach out of soil.

3. ANHYDROUS AMMONIA: Anhydrous ammonia is most effective when applied to soil in a dry state, a week before the sowing of the crop. Since it is under pressure it is injected into the soil at a depth of 12–15 cm. The dry soil absorbs it quickly and ammonium ions are retained on the soil particles. These ions go into solution under wet conditions and are absorbed by the plant. Anhydrous ammonia can be used on all soil types, but its fixation in calcareous and saline alkali soils is more than in acidic soils. Farmers in the U.S.A. prefer to use it on lighter soils well supplied with lime. They avoid using it on heavy soils. But it is extensively used in soils of acidic nature where lime is used as soil amendment.

Anhydrous ammonia can be used effectively on paddy lands a few days prior to transplanting by releasing it in running water. The disadvantage in this method is that it is absorbed to a larger extent close to the point of application than at the farther end of the field, so that the crop cannot uniformly utilize nitrogen all over the land. Some experimental work conducted at the Hebbal Farm, Mysore State, has confirmed the above observations.

Generally, the loss of nitrogen is more from the loose, light soils which have low clay and organic matter content. The injected anhydrous ammonia escapes as gas into the atmosphere. The loss may amount to 33 per cent as against a normal loss of 3–5 per cent. Application of small quantities of well-decomposed organic matter and well incorporated in the soil helps in its high degree of retention in such light soils.

4. AMMONIUM SULPHATE: It is an acid-forming fertilizer and is most pre-eminently suitable for neutral, calcareous, saline and alkali soils. Although for short-term use it can be very effective on acidic lands, its long continued use may deteriorate such soils and availability of calcium, phosphorus and potassium may be further reduced. It is only the long, continued use in large doses which is detrimental for the growth of crops.

Ammonium sulphate can be safely applied to light as well as heavy soils. The ammonium ion is absorbed on the surface of clay and humus particles and is quite readily released for the use of the crop. In wet lands as well as dry lands its use is equally effective. The loss of ammonium is very little in either of these conditions. Experiments in California have shown that on wet lands under paddy, ammonium sulphate on equal nitrogen basis is twice as more effective as sodium nitrate or calcium nitrate, as leaching of ammoniacal nitrogen does not occur to the same extent as of nitrate nitrogen on such soils.

In India ammonium sulphate is the most popular fertilizer for all agro-climatic situations. It is as much in demand by tea planters as by the paddy growers or wheat- and *bajra*-cultivating farmers. Tea is planted on slopes of hills while *bajra* is cultivated on rolling sands. Both have low retentive capacity of soil moisture. In the highly leached condition of paddy farming and the most retentive soil moisture conditions of wheat cultivation, ammonium sulphate is preferred to other fertilizers.

5. AMMONIUM SULPHATE–NITRATE: Only about one-fourth of its nitrogen is in the nitrate form; the rest is in the ammoniacal form. Therefore, its suitability to soil types is almost similar to that of ammonium sulphate. On heavier soils where leaching occurs at a reduced rate this fertilizer should be preferred to ammonium sulphate, as most plants in early stages prefer nitrate nitrogen for their growth and this fertilizer provides it in the initial stages. On lands where paddy is transplanted or paddy is grown under irrigation this fertilizer is very suitable for application.

Its acid-forming character is less pronounced than that of ammonium sulphate. It neutralizes 93 parts of calcium carbonate in the soil as against 110 parts by ammonium sulphate when applied on equivalent nitrogen basis. Thus, it is more safe to apply it on highly acidic soils than ammonium sulphate.

6. AMMONIUM NITRATE: Ammonium nitrate is one of the best fertilizers for dry-land crops, where leaching is not pronounced because half of its nitrogen content can be utilized in the early stages of growth of the crop and half for later growth. Consequently its effectiveness will be more on heavier than lighter soils. It is a fertilizer quite suitable for soils of alkaline, neutral or acidic reaction. Although an acid-forming fertilizer, the calcium carbonate required to neutralize its acid is almost half of that required for ammonium sulphate. Thus, even a very long and continued use will not render the soil acidic.

Its use on paddy lands and in situations of high rainfall should be avoided. The nitrate portion of the fertilizer will tend to leach out of soil under such conditions.

As calcium ammonium nitrate with 20.5 per cent of nitrogen, the added lime neutralizes all its acidity and this fertilizer can be utilized on all the soils of all different reactions. But particular care should be taken to apply it to soils where leaching is not heavy. It is a good fertilizer for heavy and loamy soils which are not subject to heavy leaching. Application to sandy soils should be in split doses for long-duration crops of sugarcane, cotton, chillies and others.

7. AMMONIUM CHLORIDE: This is another acid-forming fertilizer. It is slightly more acidic in nature than ammonium sulphate. In soils which contain large amounts of sodium chloride, the application of this fertilizer is not desirable as excess of chloride produces toxicity in crops. It can be applied to light as well as heavy soils without much loss of nitrogen. Most of its nitrogen is absorbed on the soil particles. Addition of organic matter to very light sandy soils helps in retention of ammoniacal ions on humus particles. In soils, which contain adequate quantities of lime, its constant application over long periods would not prove detrimental to crop production. As far as possible its application to highly acidic soils should be avoided for the consequent hazards when used continuously over long periods.

8. MONO- AND DIAMMONIUM PHOSPHATE: These are, as already stated, fertilizers primarily for use on legume crops including pulses which require well-aerated conditions. Therefore, these fertilizers can be safely applied to soils which have acidic, neutral or alkaline reaction. The nitrogen is temporarily held by the clay and humus particles until it is required by the crop for

growth and development. These fertilizers can be used on light as well as heavy soils without much loss of nitrogen soon after application. Best response, however, will be obtained from neutral loamy soils in which phosphate will be largely available for crop growth simultaneously with the ammoniacal nitrogen of these fertilizers.

9. UREA: Well-aerated dry-soil conditions are necessary for urea to decompose and get converted into ammoniacal nitrogen. Urea is always applied to dry land and after a week water can be let in for paddy cultivation or the dry-land crops can be seeded in the field. This fertilizer is less acid forming than ammonium sulphate and can be applied to soils of wider range of soil reaction than the latter. Its acid equivalent is 80 as against 110 of ammonium sulphate. Loss of urea nitrogen may be occasioned if anaerobic conditions prevail in the soil during the process of decomposition. Under such conditions ammonia will escape from the soil. Cultivation of soil prior to deep application of the fertilizer in the reduced layer is helpful in making available, larger amount of nitrogen from this fertilizer. In light soils there should be enough of organic matter available for all the ammoniacal nitrogen to be retained on the particles of the soil on decomposition of urea. There is very little likelihood of the loss of ammonia occurring in well-aerated loamy and heavy soils.

10. CALCIUM CYANAMIDE: Calcium cyanamide is a base-producing fertilizer and requires well-aerated soil conditions for its reduction into ammonia before its nitrogen can be taken up by the crops. Its basicity is three times as high as that of sodium nitrate, and is advisable for use on acid soils.

The amide nitrogen is not directly absorbed by corps. It must decompose. For dry-land crops as well as for paddy land it should be applied at least three weeks in advance to enable it to decompose and release ammonia. The open soils with high retentive power for ammonia are best suited for application of this fertilizer. In very light soils of coarse sand of soils of gravelly nature, its use is not desirable unless they have high content of organic matter.

(*d*) *Criterion for selection*: The most profitable fertilizer to the farmer is that which will cost less per unit of plant food, will give high response in crop production, can be safely and easily handled in the field, keeps its physical condition intact during storage, maintains the fertility and physical condition of the soil at its optimum, and can be sold in containers which he can use over and over again, and will not cause deterioration of the container quickly. These are conditions which guide the farmers in the purchase of straight, compound or mixed fertilizers.

Although anhydrous ammonia is a nitrogenous plant food which costs the least, its use has not yet been adopted by the farmers in this country. The difficulties in transport and method of application stand in the way of its extensive use in the field.

Urea is an organic, high analysis, solid fertilizer. It is to be manufactured on a large scale in this country. It will be 15–20 per cent cheaper to apply this fertilizer than ammonium sulphate, as its transport, stocking and bagging costs are less. Because of the hygroscopic nature the urea requires special precautions in storage. It should be stocked in alkathene-lined bags. Its response to wheat, paddy and other crops is as high as that with ammonium sulphate, provided it is applied about a week before transplanting or sowing of the crop at a depth of 10–12 cm. For application to paddy pelleting the material with clay mud and embedding the dry pellets into the soil in a transplanted crop is as effective as ammonium sulphate top-dressed to the paddy in the field. Because it is hygroscopic its application on dry days is suggested.

Ammonium nitrate is another high analysis nitrogenous fertilizer. It is extremely hygroscopic and liquefies under monsoonic conditions. It offers difficulties to farmers in storage and handling, particularly when under village conditions, where special storage facilities for stocking an inflammable material do not exist. Therefore, most of the ammonium nitrate is converted into calcium ammonium nitrate which offers no hazards of storage and handling of the product. The cost of nitrogen in calcium ammonium nitrate compares favourably with that in ammonium sulphate. The availability of nitrogen in nitrate and ammoniacal forms is a distinct advantage for most of the dry-land crops.

Ammonium chloride, containing 25 per cent of nitrogen, has very good physical properties. It can be handled and stored easily without any hazards. Since it is a by-product of the soda-ash industry its cost of manufacture in the country is likely to be less than that of ammonium sulphate. In recent experiments the response to ammonium chloride in paddy and other crops has been found to be comparable to ammonium sulphate on equivalent nitrogen basis. It should not be mixed with muriate of potash due to the toxicity of chlorine in the mixture.

Ammonium sulphate-nitrate has a distinct advantage over ammonium sulphate as it contains about 6 per cent of its nitrogen in nitrate form which is more readily assimilated by all the crops in their early stages of growth. For latter stages the ammoniacal nitrogen is taken up by the crops. The response compares favourably with the standard fertilizer. The cost of nitrogen in this fertilizer is slightly less than in ammonium sulphate. It offers little difficulty in storage and handling. It is fairly free flowing in the drill. This fertilizer cannot be so freely mixed with superphosphate, potassium chloride or potassium sulphate. In fact it should be mixed just before application to the field with phosphatic and potassic fertilizers.

Mono- and diammonium phosphates as nitrogenous fertilizers have good physical properties from the aspect of storage and handling. They can be readily mixed with potassium fertilizers. The cost of nitrogen in these fertilizers is slightly more than in ammonium sulphate. They can be safely mixed with the latter material.

Except for its high cost ammonium sulphate is the ideal nitrogen fertilizer from the farmers' point of view. They can stock it well under all weather conditions. It requires a few precautions in handling. It is the principal nitrogenous fertilizer which is mixed with phosphorus and potassic ones. In this country the manufacture of sulphate of ammonia will be continued for use in mixed fertilizers. Under wet-soil conditions its nitrogen gives the highest relative response in crop production compared to other sources of nitrogen. Except in very highly acidic soil conditions, its continuous use does not deteriorate the physical condition of the soil. Besides, it is a good source of sulphur for plants and helps to correct the alkalinity in the soil.

PHOSPHATIC FERTILIZERS

Classification and importance. Phosphatic fertilizers are broadly classified on the basis of their solubility. The two types recognized are water soluble and citrate soluble. The various phosphatic fertilizers and their composition are given at p. 140.

Most common in use of all the phosphatic fertilizers is the single superphosphate. In recent years the production of triple superphosphate has been increasing at a very fast rate. Considerable quantities of rock phosphate are dressed to highly acidic soils. This is ground to very fine mesh and then applied to the soil. Finer the powder of the material greater is the availability of P_2O_5 to the crop. Similarly, use of bone-meal is localized to areas where the soils are highly acidic in nature. The collection, digestion and grinding cost of bone-meal is rather high and, hence, the material is not processed locally as phosphatic fertilizer. Basic slag is largely consumed in the continental countries, especially in Germany, France, Czechoslovakia and Austria where it is a by-product of the steel industry and is readily available in large quantities. It has relatively high content of P_2O_5. Its use in India has not yet been taken up due to the low content of P_2O_5 in the material. Calcium metaphosphate contains very high percentage of citrate-soluble P_2O_5. The process

Name of fertilizer	Solubility	Percentage composition		Acidity or alkalinity	Phosphorus availability
		P_2O_5	N		
Bone-meal	Citrate soluble	25.28	1.2	Alkaline	70
Phosphate	Citrate soluble	30.35	..	Alkaline	30
Single superphosphate	Water soluble	16	..	Neutral	90
Triple superphosphate	Water soluble	43	..	Acidic	95
Calcium metaphosphate	Citrate soluble	63.6	..	Acidic	..
Basic slag (Indian)	Citrate soluble	3.4	..	Alkaline	..
Basic slag (European)	Citrate soluble	11.0	..	Alkaline	80
Monoammonium phosphate	Water soluble	48.0	11.0	Acidic	100
Diammonium phosphate	Water soluble	54.0	21.0	Acidic	100
Dicalcium phosphate	Citrate soluble	26.0	..	Acidic	..

of its manufacture is rather complicated and its manufacture has not extended very far. It is proposed to take up the manufacture of diammonium phosphate in this country. The power requirements for the manufacture of mono- and diammonium phosphates appear to be high and, therefore, their manufacture in other countries has not expanded very much. Dicalcium phosphate is again a citrate-soluble fertilizer and its cost of manufacture is not less than that of superphosphate. Therefore, the manufacturers are reluctant to take it up.

Process of manufacture

Bone-meal: From time to time attempts have been made to ban the export of bone from the country, but the response to crops and the cost of crushing bones have not proved so remunerative so as to ban its export. Most of the bones in the country are now largely processed at Calcutta, which is the chief export market for this commodity. The crushed material is separated into two parts after the removal of gelatin. The finer material is steamed and exported chiefly for feeding livestock as base material for mineral flour and the coarser material is utilized as by-product for bone-meal fertilizer. The principal importer of Indian bone-meal is the United Kingdom.

Rock phosphate: The mining of rock phosphate was first taken up in Great Britain in 1847. Thereafter other countries took up its mining. During 1890 to 1900 the mineral deposits were explored in Florida and North Africa. High-grade rock phosphate is found in Morocco, Algeria, Tunisia, the U.A.R. and Pacific Ocean Islands of Nauru, Christmas, Makatea, etc. The U.S.A. has large deposit which are estimated at 3,332 million tonnes. This is more than one-fourth of the world's known deposits. Morocco has a larger deposit than the U.S.A. and is about 21,336 million tonnes. According to the Geological Survey of India the phosphate rock deposits of India are estimated at 8,258,000 tonnes. Major portion of these deposits are found in Tiruchirapalli district of Madras. Singhbhum deposits do not exceed about half-a-million tonne. Since the cost of collection and processing of Trichy-nodules is very high, most of the requirements of rock phosphate are met with from North Africa. Rock phosphate is pulverized to pass 200 mesh-screen (6,200 openings per cm^2).

Superphosphate: Superphosphate was first manufactured from bones by digesting them with half their weight of sulphuric acid diluted with three or four parts of water by Liebig in 1840. Lawes in 1842 used rock phosphate, the principal constituents of which are phosphorus and lime. The sulphuric acid acts upon lime in the rock phosphate and forms sulphate of lime and monobasic phosphate. Initially sulphuric acid was stirred with iron ladles to initiate the chemical action. After treatment the material was taken out and allowed to cure and dry.

For large-scale production originally the mixing pit was used. From it, the 'den', which could hold 30.48–60.96 tonnes of superphosphate, was evolved. During the period 1900 to 1910 it was largely mechanized. In a revolving den the rock phosphate is fed forward by a screw, and the reaction with sulphuric acid takes place and superphosphate is pushed out. By 1925 to 1930 all the manufacturing operations were mechanized. A large-scale plant now consists of conveyors which move the ground rock phosphate from the mill to the storage site. From there it is conveyed to the mixer after automatic weighing and feeding of ground rock phosphate and acid. These are then fed into a mechanical den. The superphosphate is excavated from the den by a revolving knife. The discharged material is mechanically elevated up to adjustable conveyor's hand, which heaps it up in a pre-determined spot. From there, it is lifted up and carried to disintegrators and then filled up in bags. The reaction which takes place in the den may be expressed as under:

$$Ca_3(PO_4)_2 3CaF_2 + 7H_2SO_4 — 3Ca(H_2PO_4)_2 + 7CaSO_4 + 2HF$$

Thus, the phosphate present in the apatite mineral is converted into water-soluble phosphate (monocalcium phosphate). In the process gypsum and hydrofluoric acid gas are formed. The amount of monocalcium phosphate depends upon the raw material used in its manufacture. The P_2O_5 content varies from 16–20 per cent. In India all the superphosphate-manufacturing concerns use rock phosphate imported from Morocco. Singhbhum rock phosphate is mixed to a small extent and is mostly processed for use as direct raw material fertilizer.

Triple superphosphate: Its manufacture was started in 1905 in Europe and in 1910 in the U.S.A. There are two processes namely wet process and electrolytic process, by which the triple superphosphate is manufactured. The wet process consists of feeding the ground rock phosphate into vats along with sulphuric acid and wash water containing phosphoric acid. Gypsum is separated from the liquid and the muddy liquor is collected into settling tanks arranged at a lower level. There the liquor is agitated. After agitation for some time the mixture is forced through filter presses of rubber or lead. The charge in the press is washed with water under pressure until the effluent only tests 0.25°C Beaume. The wash contains 3 per cent of P_2O_5. This is then concentrated to 50° Beaume, to be used in the second stage of the process, when phosphate rock is treated with phosphoric acid instead of sulphuric acid. The product thus obtained is artificially dried.

The electrolytic process consists of calcining or smelting of the rock phosphate mixed with silica and pulverized coke. The smelting is carried out in an electric furnace. Electricity is passed to the furnace through 75 cm diameter carbon electrodes. The smelting is carried out at 1,322°C. This gives out carbon monoxide. The molten slag is formed by mixing of calcium oxide of rock phosphate with silica. This is removed separately. The free phosphorus as vapour is cooled into a liquid which is diluted to 50° Beaume and brought in contact with rock phosphate in the second stage. The resulting chemical reaction is as follows:

$$Ca_3(PO_4)_2 3CaF_2 + 14H_3PO_4 — 4 Ca(H_2PO_4)_2 + 2 HF$$

Triple superphosphate contains two-and-a-half times the P_2O_5 contained in single superphosphate. The 'wet' process will continue to be employed where sulphuric acid is cheap. The electrolytic process requires low-priced power for its manufacture. Due to limitations of both, the manufacture of triple superphosphate has not yet been taken in hand in spite of the fact that it is definitely advantageous for the farmers to apply it to their soil in preference to single superphosphate.

Calcium metaphosphate: Calcium metaphosphate is manufactured by the Tennessee Valley Authority. Phosphorus is burnt in a furnace, where hot, gaseous, combustion products pass through lump rock phosphate packed in the upper chamber of the furnace. The hot phosphorus vapour and rock phosphate chemically combine to form calcium metaphosphate which contains 62–64 per cent of citrate-soluble phosphoric acid.

Basic slag: Basic slag is a by-product of the steel industry. The impurities in the iron, consisting of silica, phosphorus, etc., are fluxed with lime and slagged-off in the open hearth furnace process. The slag material is cooled, finely ground and bagged. The European basic slag contains 8–10 per cent P_2O_5, of which 60–90 per cent of P_2O_5 is citric soluble. Basic slag also contains traces of Zn, Cu, Mn and Bo. The basic slag produced in Tata Iron and

Steel Company hardly contains 3–4 per cent P_2O_5, which does not favourably compare per unit cost with single superphosphate manufactured in the country. The slag fluxed by the new steel plants may have 5–6 per cent P_2O_5, which can be utilized for crop production at a cost comparable to effective P_2O_5 in superphosphate.

Mono- and diammonium phosphate: In wet process of the manufacture of triple superphosphate the phosphoric acid is neutralized by ammonia. The reaction is as follows:

$$NH_3 + H_3PO_4 - NH_4H_2PO_4$$

The concentration of phosphoric acid through which ammonia gas is passed is 75 per cent. When the reaction is on, considerable heat is generated which thickens the liquid; on cooling it is crystallized into a solid mass. The mother liquor is drawn off and the crystals are dried.

When the ammonification of phosphoric acid is allowed to proceed further and the pH value of the slurry is maintained at 5.8–6.0, the resulting product is diammonium phosphate. The reaction is represented as under:

$$2NH_3 + H_3PO_4 - (NH_4)_2PO_4$$

Like the monoammonium phosphate it is water soluble and is an acid soil-forming fertilizer.

Dicalcium phosphate: It is formed by the contact of orthophosphoric acid with calcium oxide of rock phosphate. The reaction is given below:

$$H_3PO_4 + CaO - CaHPO_4 + H_2O$$

In the National Chemical Laboratory, Poona, it has been prepared on a semi-commercial scale, where use of sulphur has been eliminated. The reaction may be represented as under:

$$[Ca_3(PO_4)_2]_3CaF_2 + 4H_3PO_4 - 10\,CaHPO_4 + 2HF$$

The phosphoric acid is derived from rock phosphate by using hydrochloric acid. This acts upon rock phosphate and produces dicalcium phosphate and hydrofluoric acid. The present estimated cost of production is high. The importance of this fertilizer lies in the fact that it can be substituted for superphosphate when the available sulphur supplies are limited.

Suitability to different soil types

Bone-meal: As already stated it is not a water-soluble phosphatic fertilizer. It takes time to be available in soils of neutral and alkaline reactions. It is most suited for acidic soils of pH range of 3.5–6.5. Its nitrogen is readily available under all the conditions. Bone-meal can be applied to light, medium and heavy soils. Its efficiency increases when organic matter is present in adequate quantities. The phosphorus availability from bone-meal is higher in wetter soil conditions than in dry lands. It is more profitable to apply this to red and laterite soils in Assam, West Bengal, Bihar, Orissa, Andhra Pradesh, Tamil Nadu, Kerala and Maharashtra, where rainfall exceeds 150 cm a year.

Rock phosphate: The effectiveness of rock phosphate is much more on acidic than on alkaline soils. The phosphorus in this fertilizer is citrate soluble. It does not dissolve in soil water so readily and remains fixed in the material unless large doses of farmyard manure or green manure be frequently added to the soil. It has proved very effective in highly leached soils of Kerala and Mysore states on which paddy is cultivated. The availability is not affected by the water-retentive power of the soil. It is very much in demand in Kerala State. The effectiveness is enhanced by mixing it with superphosphate and by finely powdering the material.

Superphosphate: Superphosphate is a suitable fertilizer for soils of all kinds. But its response is maximum on neutral soils, as fixation of phosphorus more or less occurs on acidic and calcareous and alkaline soils. In medium heavy and heavy soils the response to application of superphosphate is slightly more than on lighter soils because of low level of other nutrients. High response to superphosphate has been observed on alluvial soils of north Bihar, eastern Uttar Pradesh, south-east Punjab, gravelly soils of Mysore; medium response in alluvial soils of south Bihar, eastern Madhya Pradesh, central U.P., West Bengal, Orissa, Andhra Pradesh and Maharashtra; and poor response in black cotton soils of Maharashtra, Madhya Pradesh, Rajasthan and Andhra Pradesh. Since single and triple superphosphate are equally water soluble the distinction between the two with respect to suitability to soil type does not exist.

Calcium metaphosphate: The trials conducted at the Indian Agricultural Research Institute, New Delhi, did not reveal its usefulness on alluvial soils. Since it is a citrate-soluble fertilizer it is likely to prove very beneficial on acidic soils of Assam, West Bengal, Bihar, Orissa, Mysore and Kerala.

Basic slag: Even with very responsive crop of berseem the basic slag, obtained from Tata Iron and Steel Company, did not show response on alluvial soils when suppplied on equivalent P_2O_5 basis as compared to superphosphate. It is only citrate soluble and, therefore, its P_2O_5 will be available to crops on soils of acidic reaction. The material must be ground into a very fine state before application to such soils. The availability will be slightly more under wetter soil conditions which contain high content of organic matter.

Mono- and diammonium phosphate: These fertilizers have been found very suitable for most of the Indian soils. In fact the farmers are very keen to have ammophos of the composition 20:20 which has water solubility. Since these can be easily mixed with ammonium sulphate the farmers can bring its nitrogen by mixing to a level equal to P_2O_5 in any of these fertilizers. These can be used equally efficiently on light, medium and heavy soils. The response is most pronounced on medium-heavy soils because of their high productivity compared to light soils. These are equally effective in wet and dry lands. In all the states of India there is great demand for these fertilizers.

Dicalcium phosphate: Although dicalcium phosphate is a citrate-soluble fertilizer, recent experiments have shown that it is equally effective on soils of acidic, neutral and alkaline reaction. Possibly on highly calcareous soils of north Bihar and eastern Uttar Pradesh where the fixation of phosphate is high, it may be a less suitable fertilizer. Its effectiveness relative to superphosphate is somewhat higher on acidic soils than in those with alkaline reaction. In such situations response under wetter conditions is more than under dry conditions.

POTASSIC FERTILIZERS

Classification and importance. The chief sources of potassium fertilizers are the mineral cannallite ($KCl\ Mg_2Cl\ 6H_2O$), kainite ($KCl\ MgSO_4\ 3H_2O$), langheinite ($K_2SO_4\ 2MgSO_4$) and sylvite (KCl). The world deposits are estimated at 40.64–57.91 million tonnes of K_2O. Germany and Russia own the bulk of them. Some potassium chloride is extracted from salt bittern. The composition of potassic fertilizers is given as under:

Of these fertilizers the chief commercial ones are the sulphate and muriate of potash. The others are relatively of very little importance. Both these potassic fertilizers are imported from foreign countries. The manufacture of muriate of potash from salt bittern is being taken up on a pilot scale at the Central Salt Research Institute, Sambhar, Rajasthan. The production will start with seven tonnes a day will be ultimately raised to 203.2 tonnes per day when taken up on a factory scale. In recent years the requirements of potassium fertilizers have been rapidly increasing, and these have been only partially met with by imports from abroad.

CLASSIFICATION AND COMPOSITION OF POTASSIC FERTILIZERS

Source material	Water-soluble potash (K_2O) (per cent)
Potassium carbonate ..	65
Potassium chloride (muriate of potash)	60–62
Potassium chloride (muriate of potash) ..	20
Potassium magnesium sulphate ..	21–30
Potassium sulphate ..	48–52
Potassium nitrate ..	44
Sodium potassium nitrate ..	15
Bittern potash ..	7
Wood-ash ..	51

Process of manufacture

Potassium sulphate: It is largely extracted from minerals of kainite and langheinite. The first source of potash fertilizers were the Stassfurt mines of Germany. Subsequently potash deposits have been discovered in France, Spain, Poland, Russia, the U.S.A., Canada and Palestine. These minerals are first dissolved in water. Thereafter, they are fractionally crystallized to obtain potassium sulphate. The fractionated product of potassium sulphate is then separated from the mother liquor and dried. This product contains 48–50 per cent of K_2O.

The second process is to treat potassium chloride with sulphuric acid to obtain potassium sulphate. The reaction is given below:

$$2KCl + H_2SO_4 - K_2SO_4 + 2HCl$$

The salt in solution is concentrated by evaporation, crystallized and separated from the hydrochloric acid.

Potassium chloride: Cannallite and sylvite are the two minerals from which muriate of potash is obtained. The potash salts are mixed by explosives or by scraping. The salts are brought up by modern conveyor and modern transport system to the raw salt-grinding plant. From there it is conveyed to the loading station and lifted to the factory above ground. The secondary constituents of the mineral constitute 85 per cent of the crude salt. The refining process represents well-planned use of physico-chemical equilibrium of salt solution and fractional crystallization.

It is also produced from salt bittern and brines. This again requires fractional distillation and crystallization.

Suitability to different soil types

Potassium sulphate: Response to potassium sulphate has been obtained on all soils in India which are deficient in potassium. The SO_4 (sulphate) ions are retained by soils more strongly than Cl (chloride) ions but less strongly than PO_4 (phosphate) ions. In soils which have high content of calcium the SO_4(sulphate) ions are retained more than in soils of low calcium content. Thus, application of potassium sulphate generally will be more appropriate in soils of calcareous nature and alkaline reaction. Under wet conditions it is preferable to apply potassium sulphate than potassium chloride. This fertilizer will be more effective on light and medium soils than on heavy soils where aeration of crop suffers. Similarly in compact soils uptake of potassium from potassium sulphate is restricted due to limited oxygen supply. Ploughing of such lands increases the uptake of potassium. In highly leached acid soils sulphur deficiency is acutely observed. Under such conditions application of potassium sulphate is to be preferred to potassium chloride. It contains 39–48 per cent of sulphur.

Potassium chloride: In recent years the import of muriate of potash has been increased as it contains 62 per cent K_2O than the 48–52 per cent of K_2O in potassium sulphate. Based upon the chemistry of chloride ion in the soil it is inferred that under acidic soil conditions it replaces OH ions associated with the free iron oxides and, therefore, in such soils muriate of potash is likely to give more response than sulphate of potash. Besides, chlorine ions are less strongly retained on soil colloids than sulphate ions. It can be more safely used on heavy soils where chlorine ions will not accumulate very much. In alkaline soils the accumulation of chlorine ion proves toxic for crops. In potash-deficient soils with alkaline reaction it should be used along with organic matter.

Criterion for selection. When the cost per 45.3 kg of the fertilizer is the same for potassium sulphate and muriate of potash the latter is to be preferred to the former, as it contains higher content of potassium. In alluvial soil tracts and most of the black cotton soil areas on equivalent price of K_2O basis, the sulphate of potash is a preferred fertilizer, while muriate of potash is suitable for acidic areas of the country. Both the fertilizers being non-hygroscopic can be mixed with other stable fertilizers such as superphosphate and ammonium sulphate.

OTHER FERTILIZING MATERIALS

Gypsum. Although it is essentially a soil amendment in soils where sulphur deficiency is manifested, applications at the rate of 100–200 kg per 0.45 hectare are suggested. This may bring about 50 per cent increase in yield of a crop like lucerne. Sulphur deficiency has been reported from Poona. When sulphate ion carrying fertilizers, such as sulphate of ammonia, sulphate of potash and superphosphate, are applied in large dressings, there may not occur the need for application of gypsum to meet sulphur deficiency in soil.

Magnesium sulphate. In calcareous soils the high level of calcium depresses the uptake of magnesium and potassium. Application of magnesium sulphate as spray or by soil application is necessitated sometimes when enough of phosphate is not being taken up by the crop. Addition of magnesium to the soil increases the uptake of phosphorus. This is the reason why sometimes finely ground magnesium containing rock of olivine and serpentine are added to superphosphate.

Sodium chloride. Although sodium is not an essential element, yet some crops grow better when adequate quantities of sodium are available to them. Some of the very responsive crops are celery, marigold, sugar-beet, Swiss chard, table-beet and turnip. In the U.K. a dose of 254 kg of sodium chloride or agricultural salt to sugar-beet was found to increase its sugar content by 260 kg per 0.40 hectare.

Ferrous sulphate. This is commonly used to treat iron chlorosis in plants. This deficiency is particularly noticed in high calcareous soils, and is sometimes due to deficiency of potassium or by over-manuring with phosphates on neutral and calcareous soils. It may also occur in soils high in available zinc, and where copper and manganese are available in excess. The deficiency can be cured by spraying with ferrous sulphate

Manganese sulphate. The deficiency of manganese is reported on calcareous or peat soils which have been recently limed. Manganese may be present in unavailable form. In alkaline soils the availability of manganese is low and availability increases as soil becomes acidic in nature. In overlimed soils spraying of manganese sulphate at the rate of 1.12–2.25 kg|ha cures the plant of the deficiency. For peat soils 45–56.25 kg|ha is the requirement.

Zinc sulphate. The zinc deficiency occurs in heavy clay soils during wet weather. In marsh lands and in sandy soils which contain peat and are neutral or slightly acidic in reaction, it shows up in a very pronounced manner. This deficiency can ordinarily be met with by growing crops which extract zinc from the soil efficiently and by green manuring. Application at the rate of 1.12–2.25 kg|ha in spray is necessary to meet the deficiency.

Copper sulphate. In very sandy and gravelly soils in Australia and South Africa copper deficiency has been noticed. There seems to be an interaction between zinc and copper because in the presence of copper there is response to zinc. Copper is applied as copper sulphate (2.8–5.6 kg|ha) depending upon its deficiency in soil.

Molybdenum oxide. The requirements of molybdenum are extremely small. It sometimes occurs in acid sandy soil and particularly experienced by legumes. In light sandy loam soils of Delhi berseem gave good response to it. The dressing per hectare varies from 0.07–0.56 kg per ha of molybdenum oxide or 0.56–2.25 kg of ammonium or sodium molybdate.

Borax. Boron may be present in adequate quantity, but soil conditions may be such that is availability may be low to the crops. Normally it occurs when acid soils are overlimed and appears more in dry than wet years. In highly leached soils boron availability is low. About 4.5–9.0 kg is usually adequate to meet the deficiency of the nutrient. It cannot be applied as spray but has to be dressed to the soil in small, frequent doses to avoid excess toxicity to the crops.

FERTILIZER MIXTURES

General. Mixed fertilizers have become very popular in countries where fertilizer dose is extremely popular. Some of the fertilizer mixtures have been adopted in India by farmers, particularly in the south. Most of these mixtures have been popularized by fertilizer-mixing concerns. The mixture first became popular to boost up sales of superphosphate in various countries. Some of the manufacturing concerns were apprehensive that superphosphate sales may drop off if the farmers took to applying nitrogen or potash separately. Besides, these manufacturing firms wished to have lead in sales of their product over others by balancing the nutrients required by crops on various soils which were deficient in different nutrients.

Advantages and disadvantages of using fertilizer mixtures. There are several advantages in the use of fertilizer mixtures. In labour-scarce areas there is a saving in the cost of application of fertilizers. Sometimes, the mixture of fertilizers has better physical condition and can be drilled easily into the soil. This advantage is particularly marked when the mixture prepared is a granular one. In mixed fertilizers the plant nutrients required in small quantities are applied more evenly than if they had been applied singly. When the mixture has been prepared on a scientific basis suited to the crop and in consonance with the deficiency of nutrients in the soil, the farmer is assured of right proportion of plant nutrients in the soil.

The disadvantages also are many. The individual nutrient may be required at specific time by the crop to meet its need. The mixture cannot meet the need. There is less effective control on the part of the farmer regarding the quantity of plant food present in the mixture. He has to rely entirely on the grade advertised by the firms mixing plant food. When several fertilizers are mixed to prepare the mixture for a given weight of nutrients more fertilizer is handled and transported. This increases the relative cost to the farmer. Besides, the mixture-manufacturing concerns charge the cost of compounding, which the farmers have to pay. Since farmers in the country are illiterate and most often do not maintain touch with the Departments of Agriculture regarding the mixture, they may be applying too little of some nutrients and unnecessarily large amounts of the other.

Most of the firms do not declare the various fertilizers used to prepare the fertilizer mixtures. Such a mixture is termed 'closed formula' mixture, but others do and it is termed as 'open formula' mixture. The advantage in the latter case is that by knowing the formula one is informed of the kind of plant nutrient present in it with respect to its suitability for specific soils and crops.

Fillers and conditioners. When mixtures are compounded it is often necessary to add some material which does not contain plant food (NPK) of major nutrients so that requisite grade is made up. Since this material is in addition to the fertilizers in the mixture it is termed as 'filler'. It often serves only as a make-weight to balance the formula in the preparation of the grade of the mixture. In order to improve the physical condition of a fertilizer or a mixture a conditioning agent is often used to reduce caking, improve drillability, reduce hygroscopicity and so on. Such a material is known as 'conditioner'. It is sometimes desirable to add a conditioner to make a non-granular solid fertilizer into a granular fertilizer.

Till recently there was a tendency to use large quantities of fillers in the mixture, particularly so in the U.S.A. But as high-grade fertilizer demand is increasing year after year the use of fillers is decreasing. The total content of plant food in mixed fertilizers at the turn of the Century was 13.9 per cent but in 1949 it was 22 per cent and in 1953 it increased to 26 per cent. Thus, the quantity of filler is rapidly decreasing and high analysis fertilizers are being used to prepare the mixtures. The conditioners are becoming more popular as these are required in extremely small quantities and improve the physical conditions of the mixtures.

Materials for mixtures. Mixed fertilizers are compounded from a few fertilizers of the nitrogenous solid fertilizers, the most important of which is sulphate of ammonia. Other fertilizers are anhydrous ammonia, ammonium nitrate, urea and calcium cyanamide. The phosphatic fertilizer in common use is superphosphate but the industry is now turning over to triple superphosphate and mono- and diammonium phosphate. Both the potassic fertilizers, sulphate of potash and muriate of potash are used for compounding fertilizer mixtures.

The compatibility of various fertilizers for mixing depends upon the various reactions that take place, which in turn depend upon moisture conditions, temperature and fineness of particles. The double decomposition may occur in the process of compounding. As, for instance, the potassium nitrate and ammonium chloride are formed when ammonium nitrate and potassium chloride are mixed together. While preparing a mixture, actual loss of nutrients may occur. Mixing of highly basic fertilizers, such as calcium cyanamide, basic slag, quick lime and slaked lime, cause loss of nitrogen from ammonium salts, so that compatibility of fertilizing materials must be kept in view while forming mixtures. Some of these materials as well as anhydrous ammonia when mixed with superphosphate decrease the water-solubility of phosphorus in superphosphate. Urea, calcium nitrate and ammonium nitrate impart poor physical property to the mixtures as they are hygroscopic in nature. Ammonium sulphate adds to the caking of fertilizers if the mixture is not properly cured.

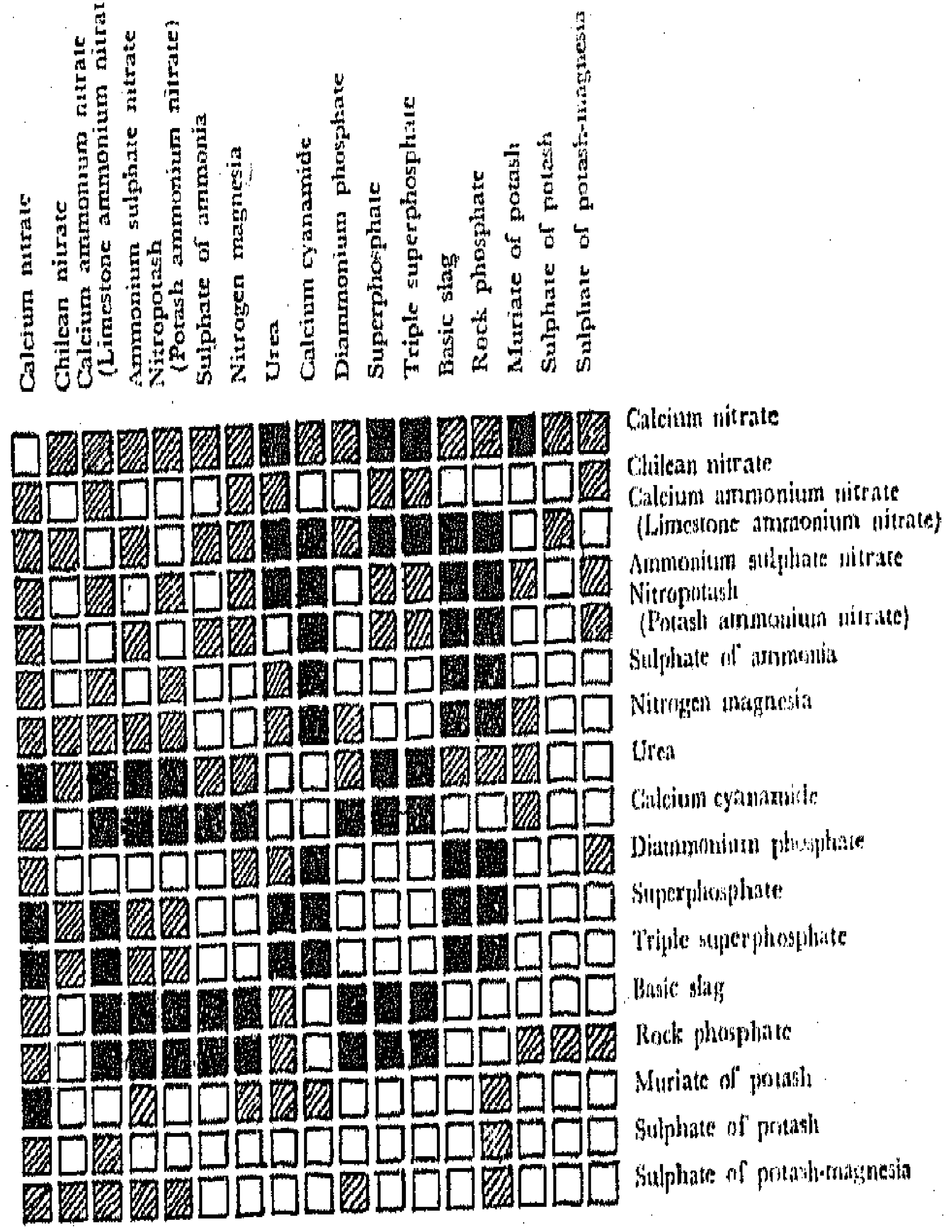
Nowadays some of the fertilizer-mixing manufacturers are mixing pesticides, fungicides and weedicides with the fertilizers to enable the farmers to reduce further the cost of application of these materials prior to sowing of the crop or after it has established itself. This simultaneously supplies nutrients to the crop, destroys weeds, and controls pests and diseases. Although the demand for such mixtures in the U.S.A., New Zealand and the U.K. is on the increase, the cost of pesticide in the mixture increases the cost of the mixture besides the compounding cost. Sometimes it is desirable to dress the fertilizers and pest control materials at different times to serve the required interests but comprehensive mixtures are less valuable than application of separate ingredients.

Mixing of fertilizers is most often cheaper than purchasing of mixed fertilizers. The corresponding chart gives the compatibility of the fertilizers for safe mixing at the farm.

Granulation of mixtures. In recent years the granulation of fertilizer materials has been taken up on an increasing scale to reduce caking of the mixture, decrease the segregation of the constituents, enable preparation of high analysis mixtures, and facilitate their drilling and application in the field. If the granulated product is hygroscopic it is bagged in moisture-proof containers for long-distance transport.

Common mixtures. From a large number of experiments conducted under Fertilizer Use Project from 1953 to 1956 it was possible to work out suitable combinations of nutrients for mixtures. Generally with wheat and rice, on most of the soils, a combination of 9 kg N + 9 kg P_2O_5 gave as good response as 18 kg N alone. The former combination proved definitely more remunerative than straight application of nitrogen. Accordingly a 9:9 NP fertilizer will soon be manufactured in the country. The relative cost per kg P_2O_5 delivered to the farmers in this mixture will be Re one compared to Rs two per kg of P_2O_5 in superphosphate.

The Indian Council of Agricultural Research has demonstrated the use of fertilizers 12:6, 12:6:6, 12:6:12 in various localities. Some of the important fertilizer mixtures in vogue in southern India are given in Table 33.



☐ Fertilizers which can be mixed and stored.

▨ Fertilizers which can be mixed but not stored longer than 2-3 days.

■ Fertilizers which cannot be mixed.

GUIDE FOR MIXING FERTILIZERS

First look up the component in question in the horizontal column and then the other fertilizers in the vertical column. The square where the two columns meet shows whether mixing is possible.

Because rock phosphate varies considerably according to its origin, the mixing qualities of rock phosphate also vary considerably. Statements above about this fertilizers' miscibility must be regarded only as a general indication.

TABLE 33. COMPARISON OF ANALYSIS OF SOME FERTILIZER MIXTURES MARKETED IN SOUTH INDIA IN 1950 AND 1957

Mixtures for	Analysis 1950				Analysis 1957			
	N%	P%	K%	Total plant food	N%	P%	K%	Total plant food
Coconut ..	7	8	8	23	8	8	16	32
Tapioca ..	6	8	8	22	8	8	16	32
Potato ..	4.5	15	6	25.5	4.5	13	7	24.5
Virginia tobacco	4	16	4	24	3	13	9	25
Sugarcane (Kerala)	10	3	2	15	8	4	10	22
Paddy (Kerala)	14	6	..	20	10	7	7	27
Paddy (Standard)	12	6	..	18	12	6	4	22

The plant food content of mixtures varied from 22–32 per cent in 1957. There was considerable appreciation in the plant food content over the mixtures in common use in 1950. The increase was due largely to inclusion of more potash in the mixtures. During the World Agricultural Fair in New Delhi, in 1959, the Fertilizer Association of India in co-operation with the Indian Institute of Public Opinion conducted a sample survey out of 20,000 farmers invited by the Bharat Krishak Samaj. A group of 528 farmers were chosen at random distributed on the basis of total cropped area in each State. The survey indicated that only 11.6 per cent of the users of fertilizers dressed their crops with mixed fertilizers.

QUALITY CONTROL

In the wake of the increasing use of mixed fertilizers various malpractices were adopted and are still in vogue. These are mixing of sand, lime, dolomite, wood-ashes, etc., to increase the bulk and reduce the content of plant food in the bag. Some mixing plants are unscrupulous and show a high composition of the mixture on the bags while the actual contents of plant food are low. In the U.S.A. every State has a fertilizer control law which operates to regulate the industry. Samples of material are drawn by the chemist of each State. These samples are analysed and the report submitted to the authorities. The fertilizer manufacturers or distributors are penalised according to the law, depending on the nature of fraud detected in the analysis report.

According to the regulations each bag must have printed, guaranteed percentage of the several ingredients claimed to be in it. The analysis printed consists of total nitrogen, available P_2O_5 and water-soluble potash in the order indicated. The analysis is carried out according to the official methods of analysis adapted by the Association of Agricultural Chemists which are acceptable to the industry as well as the official agencies. This avoids use of low-grade materials carrying constituents in very unavailable form as against producers of high-quality products, which the farmer cannot detect so readily until the produce has been harvested by them and response studied.

In order to regulate the industry the Government of India issued the Fertilizer (Control) Order, 1957, under Section 3 of the Essential Commodities Act, 1955. Minor amendments have been issued thereafter to improve its working. This order authorises Agriculture Chemists in various States to draw samples of fertilizer mixtures for testing their genuineness. It fixes the limits of purity permissible in such samples. The district authorities have been given powers to initiate proceedings against the defaulters. It is a comprehensive control order which gives directions for registration of business of fertilizer mixture, display of chemical analysis of the mixture of fertilizers and printing of grade on the bag.

This order was issued to regulate the business of fertilizer mixtures in the country from its very infancy.

MARKETING AND DISTRIBUTION

To start with, the fertilizer trade was mostly controlled by private agencies. During the World War II the programme of Grow More Food was initiated and under that programme a fertilizer pool was set up. This pool was strengthened due to large import of nitrogenous fertilizers during the past decade on Government account. Thus, nitrogenous fertilizers are fully controlled commodity. The planning for nitrogenous fertilizers starts a year ahead. The State Governments indicate their requirements month by month after taking into account of carry-over stocks. After taking note of internal production and available foreign exchange, global tenders are invited for import of fertilizers. Some fertilizers are

obtained on bilateral trade agreements. The Regional Directors of Food at the ports handle these fertilizers and despatch them, through clearing agents, to the State Governments. In some States co-operative organizations handle the fertilizers, while in others the material is handled by private marketing agencies.

The situation is different with phosphate and potassic fertilizers. The superphosphate industry is entirely privately owned. The control excercised is only under the Fertilizer (Control) Order, 1957. The important of rock-phosphate is largely controlled by the Government action to conserve foreign exchange. Since no potassic fertilizer is produced in the country, these are imported from abroad by various concerns and marketed directly to the fertilizer-mixing firms or to the wholesalers and from them to the retailers.

For distribution of superphosphate the country has been divided into four zones, namely, Southern, Eastern, Northern and Western Zones. At the zonal meetings representatives of various zones meet and discuss problems of production and consumption with the industry under the aegis of the Ministry of Food and Agriculture. The requirements of superphosphate are intimated and the firms offer commission, rebate and considerable reduction in price when firm orders are placed in advance. At these meetings measures are worked out to ensure off-season movement of fertilizers, to create conditions for planned production by the factories and for chalking out programme for distribution by the States.

Walters Jr. conducted, in co-operation with the Ministry of Food and Agriculture and the Fertilizer Association, a survey of the distribution of fertilizers. The survey touched upon various aspects of the present system of distribution of fertilizers. The survey indicated lack of co-ordination between different authorities responsible for indenting supplies, allotment of quotas within the States, propaganda for popularizing fertilizers, credit and its recovery, and other factors. Most of the indented supplies were not being received in time. The quotas allotted to one party were often transferred to another party at the last moment causing much inconvenience to the first consignee. As various types and sizes of bags for various fertilizers had not been standardized to the requirements of the farmers it resulted in spoilage, deterioration of fertilizers in transit and malpractices in sales. There was no well-organized marketing intelligence service for the farmers and fertilizer dealers.

Since 1957 the fertilizer trade has expanded from 203,200 tonnes of plant nutrients to 711,200 tonnes. The Fertilizer (Control) Order has been issued to introduce quality control and suppress malpractices. The sizes of bags have been standardized and trade is being regulated. A Phosphate Fertilizer Scheme has been initiated by the Industry which is meant to promote the sales of superphosphate in the country. Similarly, Potash Scheme of the International Potash Institute has been working to disseminate the knowledge about the value of potash in balanced fertilization of crops. The Departments of Agriculture have been taking very active interest in recent years in promoting the use of fertilizers. In 1954, the Indian Council of Agricultural Research initiated a scheme on Fertilizer Demonstrations on cultivators' fields to popularize new nitrogenous fertilizers, demonstrate response to combination of nitrogen, phosphorus and potash, and show the usefulness of fertilizer mixtures. The Indian Council of Agricultural Research has also initiated a Co-ordinated Scheme of Fertilizer Trials in all the districts of the country to work out responses to fertilizers on different soil types with various crops and thereby rationalize the use of fertilizers on a scientific basis. Thus, all the agencies on popularizing fertilizers and larger take-off of fertilizers are well organised.

Since the fertilizer industry is fast expanding there is an urgent need to decentralize the Central Fertilizer Pool and hand over the trade co-operative agencies. Some steps in that direction have already been initiated. The supplies and services of the nature of fertilizers, which were previously handled by the Department of Agriculture, will hereafter, to an increasing degree, be handled by co-operative societies. Attempt is being made to channel, on a larger measure, the sale of superphosphate and potassic fertilizers, as well as the fertilizer mixtures to be handled by co-operatives. There are, however, very many problems which need attention of the co-operative societies. These relate to proper assembling, storage, transport, risk bearing and selling of the fertilizers. In the Second Five-Year Plan there was provision to set up seed, fertilizer and implement stores in village-level circles. This programme has gone ahead but there remains much to be done. Central Co-operative Stores are still to be organized. The agency for transport of fertilizers from production and import centres to consuming centres has not been fully streamlined so that fertilizers are available to the farmers at the right time and in right quantities at a distance, not far from his place of activity.

For purchase of fertilizers the farmers need short-term credit on easy terms. The Reserve Bank of India carried out pilot project studies in Vishakhapatnam and observed that recoveries of loans on fertilizers were high, to the tune of 94 per cent. It is essential to arrange for short-term loans bearing 4.5 per cent interest so that farmers are encouraged to buy the fertilizers. At present the co-operatives charge 10–12 per cent on short-term loans which acts as a deterrent to expanded use of fertilizers in the country.

VALUATION OF FERTILIZERS

The fertilizers are valued on the basis of plant food contained in them and the availability of the plant food for crop production. On the bag the labelled plant food value is given in terms of total nitrogen, available phosphoric acid and available potash. In India the prices of 'straight' fertilizers delivered at rail-heads are fixed by the Government. Thereafter, a margin is allowed to arrive at delivered price. The value of the fertilizer or the mixture is expressed per pound of plant food or per unit of plant food. When it is expressed as per pound of plant food then the response is also expressed in similar terms. For instance, if the price per ton of ammonium sulphate (20.5 per cent N) delivered to the farmer be Rs 385, then the price per kg of nitrogen will be Rs two. Similarly, for superphosphate (16 per cent P_2O_5) the price per kg will be Rs two when price per 1.016 tonnes is Rs 255.

The method of valuation of fertilizer employed in Western countries is to express it in units. This represents 1 per cent of N, P_2O_5 or K_2O available in 1.016 tonnes or 10.15 kg. In India the former method has been adopted to study net response on the value of fertilizers. The average response to 9 kg of nitrogen in ammonium sulphate is 1.59 tonnes of paddy. The value of 9 kg N amounts to Rs 16.80, while the response of paddy valued at Rs 12 per md works out to Rs 54. Thus, the net response to 9 kg nitrogen is Rs 37.20 per 0.45 hectare. Similarly, for phosphate the average response to 0.9 kg P_2O_5 is 1.33 tonnes of paddy. The cost of 9 kg P_2O_5 is Rs 14.20 and the gross response is Rs 43.20. Thus, the net response equals to Rs 29. Normally, the net responses are worked out for optimum doses of plant food, which are experimentally determined from response curves.

CHAPTER VI

MICRONUTRIENTS

NITROGEN, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, copper, zinc, boron, molybdenum and chlorine are now accepted as essential nutrient elements for crops. Of these, the first three are more familiar as they are applied in relatively larger quantities as fertilizers to crops. The last seven, though essential for crop growth, are required in very small amounts, and as their concentration is very low in the plants, they are known as trace elements or micro-nutrient elements.

ROLE IN PLANT METABOLISM

The metabolic processes in plants are controlled by enzyme systems and the normal growth depends upon the proper co-ordination of the latter. Since micro-elements are largely associated with enzyme systems, their deficiency would bring about a disturbance of the activity of the latter and this in turn would affect the plant growth adversely. Plants of different genera and species have different enzyme systems; therefore, their nutrient requirements may vary.

Iron: It is essential for the synthesis of chlorophyll, although it is not a part of its molecule. It is incorporated in several important oxidation enzymes which are involved in the process of respiration.

Manganese: It is essential for the synthesis of chlorophyll, as intense chlorosis results under its severe deficiency. It also activates certain enzyme systems.

Copper: Copper is an essential co-enzyme for oxidase enzymes catalysing the oxidation of phenols and ascorbic acid.

Zinc: Zinc has a role in carbohydrate metabolism and probably in the turnover of organic phosphorus compounds. The production of auxins is also retarded due to deficiency of zinc.

Boron: This nutrient does not appear to be an activator nor a constituent of an enzyme complex. Its deficiency leads to abnormal differentiation of young tissues and accumulation of soluble carbohydrates and nitrogen at the expense of protein nitrogen. Its absence prevents pollen germination in many plants.

Molybdenum: Molybdenum is essential for nitrogen fixation in the soil by *Azotobacter* and by the root-nodule bacteria. It is

also involved in nitrate reduction in micro-organisms and higher plants. Its deficiency also leads to loss of ascorbic acid.

Soil conditions influencing availability of micro-elements. Plants differ in their requirements and in their ability to extract trace elements from the soil. If a plant is unable to obtain enough of a particular element for its normal requirements, a soil deficiency in that element is said to exist for that particular species, though it does not necessarily imply that the soil is deficient in that element for other species. Molybdenum deficiency, for example, occurs in cauliflowers on soils which may supply sufficient molybdenum for normal growth of other vegetables. Clovers have a higher demand for molybdenum than the grasses, because it is necessary for the nitrogen-fixing processes of their root-nodule bacteria. Other examples of plants having relatively high micro-element needs, or poor extractive power, are oats and red-beet for manganese, swedes and mangels for boron, fruit trees for zinc, and subterranean clover for copper and zinc.

Usually, only a fraction of each micro-element in the soil is accessible to plants. The proportion that is available depends on several soil factors. Of these, the soil acidity or alkalinity and the organic matter content are the most important, since these factors can be altered through cultural practices.

Iron, copper, zinc, boron, cobalt and manganese, occurring naturally in the soil, can be utilized by plants more easily under acid conditions than under alkaline conditions. On some alkaline soils plants are unable to extract sufficient copper, zinc and manganese for their requirements, although apparently adequate amounts may be present. On the other hand, some soils, both acidic and alkaline, have insufficient total supply of copper, zinc, boron and cobalt; copper deficiency in subterranean clover on certain acid sandy soils in Australia is due to this cause.

Molybdenum is the least available to plants in acid soils. Alkaline soil conditions favour its availability. Thus, liming, if overdone, may induce deficiencies of manganese, zinc, boron, copper and iron. Response of clover to lime on certain acid soils is suspected to be due to the action of lime in increasing the availability of naturally occurring molybdenum.

Soils high in organic matter, such as peaty and marshy soils, show shortage of copper. A larger than the normal corrective application may be required on such soils to overcome the absorption capacity of organic matter for copper.

Alkaline peaty soils and soils high in organic matter made alkaline by liming are subject to manganese deficiency. The availability of manganese is also affected by the aeration of the soil. Temporary waterlogging of organic soils can, by reducing aeration, greatly increase the available manganese.

High phosphate application may induce zinc deficiency and high potassium application manganese deficiency. Heavy applications of ordinary fertilizers also bring about deficiencies of microelements. As crop yield increases with intensive use of fertilizers, more of micronutrients may be removed from the soil and, thus, it might become poorer in micro-elements in course of time. Conversely, the increased growth brought about by the use of trace elements induces secondary deficiencies after a time. In Australia the infertile sandy soils brought initially into greater production through the use of superphosphate and copper on subterranean clover pastures, sooner or later, were in danger of developing potassium deficiency in the herbage.

Some soils suffer from 'hidden deficiencies' and the crops are said to suffer from 'symptomless disease'.

EFFECTS OF MICRO-ELEMENTS

Toxicity. Even if present in amounts not much above the sufficient level, the micro-elements may be poisonous. Boron is toxic when the water-soluble form is too high, e.g., poisoning has been recorded in citrus in Victoria (Australia) on soils with 2–16 ppm of water-soluble boron. Ingestion of excessive molybdenum causes scouring in stock, and this sometimes occurs in stock grazed on herbage containing a few more ppm of molybdenum than usual. In very acid soils iron and aluminium are often harmful but the most common toxicity is due to manganese. Naturally occurring toxicity due to copper and zinc has not been found in plants, but excessive uptake of copper may cause ill-health in sheep grazed on herbage of high copper content. The occurrence of micro-element excesses in nature, and the readiness with which poisoning can be induced artificially, are warnings against the indiscriminate application of micro-elements either to the soil or the foliage.

Effects. Some examples showing effects of micro-nutrient deficiency on plants and the improvement in the quality of crops brought about through application of micro-nutrients are given below:

Quality or nutritive value	*Micronutrient*
1. Decrease in Vitamin A content of spinach	Manganese deficiency
2. Increase in Vitamin C content of tomatoes and black currant	By application of manganese to soil
3. Decrease in Vitamin C of tomato and five vegetables	Molybdenum deficiency
4. Increase in Vitamin C in Chinese lettuce, Chinese red peppers and tomatoes	By application of zinc, magnesium and nickel
5. Increase in Vitamin B and biotin content of beans, maize and flax	By application of small quantities of selenium
6. Increase in thiamine and niacin content of tomatoes and turnips	Application of boron and molybdenum
7. Decrease in arginine of the protein in cauliflower	Decrease in molybdenum

ZINC

Deficiency. Zinc deficiency is due to influence of soil conditions or is caused by cultural practices.

Soil conditions. It commonly occurs in:

(*a*) acid, leached, sandy soils with low total zinc;
(*b*) alkaline soils in which zinc becomes unavailable;
(*c*) soils from granites, gneisses, etc.;
(*d*) some organic soils where zinc is tied up in forms not easily available; and
(*e*) clay soils with low Si-Mg ratios, where zinc is fixed in forms not easily available to plants.

Cultural practices. Zinc deficiency may be brought about by:

(*a*) heavy dosages or prolonged use of phosphatic fertilizers;
(*b*) liming of acid (especially sandy) soils;
(*c*) nitrogen fertilization; this effect is probably due to changes in pH or cation effects rather than to nitrogen; and
(*d*) alfalfa cover crops in orchards; the alfalfa roots may bring zinc to the soil surface followed by decomposition of tops and release of zinc, or the alfalfa roots may solubilize zinc and help other plants obtain more.

Symptoms. In several crops the symptoms due to acute zinc deficiency are well defined and renders leaf or soil analysis superfluous. However, the early stages of zinc deficiency cannot be easily identified unless leaf and soil analysis is undertaken. The visual symptoms deficiency on some important crops (cf. Chapman, 1960), are given below:

Apple (Malus sylvestris): Leaves developing in spring are characterized by whorls of small, stiff and sometimes mottled leaves near tips of current season's growth; except for terminal rosettes twigs are bare for some time; later branches may arise below twigs and produce almost normal leaves early; later these become mottled and irregular in shape; fruit bud-formation reduced; developing fruits are small and malformed; twigs may dieback after first year.

Barley (Hordeum *sp.*): Leaves are uniformly chlorotic, drying up; tip growth ceases.

Broad bean (Vicia faba): Leaves and flower buds shed; seed pods fail to develop.

Corn (Zea mays): Light yellow streaks between veins followed rapidly by necrosis in older leaves; in extreme cases young leaves, unfolding in bud, are white to light yellow.

Coffee (Coffea arabica): Reduction in length of internodes in one or more branches, and leaf and fruit size; chlorosis, which may resemble 'mottle leaf of citrus' pattern. Dieback occurs.

Cotton (Gossypium *sp.*): Leaves chlorotic with necrotic areas.

Flax (Linum usitatissimum): Greyish-brown, collapsed spots in young leaves, followed by drying and colour changes to brown or white. Internodes between leaves shortened with rosetting appearance. Latter apex of main stem becoming necrotic.

Garden bean (Phaseolus vulgaris): Leaves and flower buds shed.

Garden pea (Pisum sativum): Lower leaves necrotic at margins and tips; stems stiff and erect; flowers none.

Citrus species: Leaves chlorotic—'mottle leaf' or 'frenching' twigs tend to dieback; fruit quality and quantity affected.

Oats (Avena sativa): Leaves pale-green; older leaves with collapsed areas at margins and tips, greyish; rest grey to bronze-green; necrosis extending down the leaf.

Peach (Prunus persica): Leaves chlorotic, mottled, narrow, rather crinkled, twigs short, internodes near tips with leaf rosettes, defoliation progressing upward, fruits few, mis-shapen and worthless.

Potato (Solanum tuberosum): Leaves with greyish-brown to bronze irregular spots, initially restricted to half way up plant, and finally on almost all leaves; in extreme deficiency stems and petioles developing brown spots; plants short.

Squash (Cucurbita maxima): Leaves mottled with necrotic areas.

Sugar-beet (Beta vulgaris): Leaves necrotic with brown to greyish spots, tips withering, only petioles green.

Tobacco (Nicotiana tabacum): Lower leaves slightly chlorotic at tips and margins, followed by necrosis of chlorotic tissue, small areas at first sometimes surrounded by halo—these areas rapidly enlarge, become water-soaked in appearance; small veins at first involved in breakdown; latter veins as well as tissue between veins dry up; internodes short, leaves apparently thickened.

Tomato (Lycopersicon esculentum): Leaves mottled and necrotic, leaflets small, midrib shortened.

Mitigating zinc deficiency. The practices that mitigate zinc deficiency are as follows:

Soil fumigation or sterilization prior to planting a crop improves its zinc-supplying power or availability; alternatively this treatment reduces detrimental organisms and roots grow better. This has been noted in new citrus plantings on old cirtus soils where comparisons of fumigation and non-fumigation have been made.

Under soil conditions where organic matter in surface layers is built up zinc accumulation is favoured.

Addition of organic matter to soil or growing green-manure crops frequently improves crops subject to zinc deficiency.

Excess zinc occurs: (a) under some kinds of acid peats, (b) near lead mine dumps where soil has been contaminated with seepage, (c) in soil contaminated with zinc from mining operations, and (d) in soil derived from rock materials high in zinc.

The cultural practices which tend to bring about zinc toxicity are acidification of some soils and accumulation of excess zinc from zinc fertilization, as has occurred in some soils in Florida (U.S.A.). Zinc application may become especially hazardous where such soils become acid due to application of acid-forming fertilizers.

Zinc excess. It has been found that 400 ppm zinc in replaceable form was toxic to corn (Barnette, 1936). Calcium carbonate at 4,480 kg|ha overcame the toxicity. Staker and Cummings (1941), and Staker (1942) found some New York peat soils where zinc was present in toxic concentration varying from 0.43–10.16 per cent; most of it occurred in exchangeable form. Spinach, lettuce and carrots were severely affected. Application of sufficient sodium hydroxide or calcium hydrate to bring the pH to neutral, reduced the toxicity in soils which were not too high in zinc.

Symptoms. *Citrus, oats and sugar-beet*: Leaves show iron chlorosis.

Barley and grasses: Rusty-brown flecks on leaves and death.

Control of zinc deficiency and excess. Zinc deficiency can be corrected by spray and soil application, injection into tree trunks and inserting pieces of galvanized iron into branches or trunks of trees. Spraying trees with zinc sulphate has been more generally used with success; it is advisable to add about half as much quantity of lime or soda-ash as that of zinc sulphate to the spray solution in order to guard against injury to the foliage.

Where excess zinc occurs, application of limestone or phosphate lowers zinc solubility and absorption by plants.

The doses of zinc sulphate applied for correction of zinc deficiency is variable for different crops as indicated by Chapman (1960) are given below:

Alfalfa (Medicago sativa): 0.5 per cent zinc sulphate as syray.

Bean (Phaseolus sp.): 0.3 per cent zinc sulphate as spray when 10–15 cm high.

Tomato (Lycopersicon esculentum): Watered at setting out time with a solution containing 0.2 per cent zinc sulphate, and applied at 5400 litres/ha.

Almond (Pyrus amygdalus): Dormant spray of 6.8–11.3 kg zinc sulphate per 454.5 litres of water. In severe deficiency, a summer foliar spray of 4.5 kg zinc sulphate + 4.5 kg lime hydrate to 454.5 litres of water.

Apple (Malus sylvestris): Dormant spray of 11.3–22.6 kg zinc sulphate per 454.5 literes of water.

Cherry (Prunus avium): Dormant spray of 22.6 kg zinc sulphate per 454.5 litres of water + 5.4 kg zinc sulphate with 2.7 kg lime hydrate to 454.5 litres of water, 30 days after leaves appear.

Citrus: 2.2 kg zinc sulphate, 1.10 kg lime hydrate in 454.5 litres of water applied before spring growth cycle or in early summer. 10–5–100 formulation gave longer control.

Grape: Dormant spray containing 1.8–3.6 kg zinc sulphate per 455.5 litres of water.

Peach (Prunus persica): Dormant spray containing 6.8 kg zinc sulphate in 454.5 litres of water. Foliar sprays containing 4.5 kg zinc sulphate, 2.2 kg lime hydrate in 454.5 litres of water in spring, and a dormant spray from 4.5–22.6 kg zinc sulphate per litre were tried in Australia with success. Dormant sprays, in late winter, of 22.6 kg zinc sulphate in 454.5 litres of water were found effective in Australia.

Pear (Pyrus communis): Dormant sprays of 11.3 kg zinc sulphate in 454.5 litres of water.

Response to zinc under Indian conditions: Zinc applied directly to soil or as a spray is beneficial to agricultural as well as horticultural crops under Indian conditions. In Tamil Nadu, orange trees suffering from the mottle leaf and gradual deterioration have benefited from its application (Marudarajan, 1949). But orange trees suffering from mottling and gradual defoliation in the submontane *Kukal Shrevaroys* did not respond to zinc, manganese, iron, although spectrographic analysis of leaves showed deficiency of these elements. Guava (*Psidium guajava L.*) plantations in Pushkar Valley, suffering from interveinal chlorosis, reduced leaf size and dieback, improved after spraying with zinc sulphate (0.45 kg $ZnSO_4$ and 0.31 kg hydrated lime in 73 litres of water). Vasu deva and Raychoudhri in 1954 and Mani *et al.* in 1959 reported that spray of zinc sulphat (0.90 kg $ZnSO_4$ and 0.45 kg lime in 864 litres of water) on *malta* and orange trees suffering from chlosis and dieback in the Durgapur farm at Jaipur, Rajasthan, significantly improved. The cost of one spray of the mixture with a power-operated and hand-operated sprayer worked out at 7 and 10 paise per tree, respectively. Two sprays a year were recommended as a general protective measure in that tract. In 1966, Dhingra *et al.* noted that spraying citrus tree with 0.3 per cent zinc sulphate reduced chlorosis and increased the zinc content of the leaves. Singh in 1963 reported a significant increase in yield and better seed-set in *Brassica* species by two foliar sprays of 500 ppm of zinc. Dastagir in 1965 reported that the new yellow leaf disease of areca palm in Mysore State could be controlled by applying 113–142 kg of zinc sulphate per palm together with application of NPK. Patel and Patel in 1949 reported beneficial effect of zinc on growth as well as bud-formation of cotton. Application of zinc sulphate to soil increased the yield of American Upland cotton 'Indore 1', in Malwa tract with soil pH varying from 8.2 to 8.8. The response varied from season to season and when (in the fourth season) zinc was not applied, the increase in yield was statistically not significant. As the cost of these micronutrients was high in relation to increase in yield, these applications could only be economical if the effect of one application lasted for three years. Smaller doses of these micronutrients were not found effective. In 1956, Sadaphal and Das reported that zinc sulphate applied in addition to NPK at the rate of 5.6 kg|ha to soil, or as spray of 1.12 kg|ha increased grain yield of wheat by 190 and 271 kg|ha respectively, over the NPK treated control and total grain protein. Sadaphal and Das in 1961b also obtained good response to foliar application of zinc (16.1 per cent increase) in grain yield of wheat. Kanwar *et al.* in 1958–62 and Bhumbla *et al.* in 1963–65 observed significant increases in yield of wheat by foliar application of zinc in several trials with calcareous and acid soils, but only in a few trials with non-calcareous neutral soils. In 1964, Kanwar and Joshi also reported significant increases in wheat by foliar as well as soil application of zinc sulphate in Kangra and Kulu districts. Koraddi and Seth in 1964 obtained 15.2 per cent increase in grain yield of wheat by applying zinc sulphate (2.27 kg|ha) to the soil or (0.57 kg|ha) to foliage. Kanwar *et al.* in 1958–62 and Bhumbla *et al.* in 1963–65 studied the effect of foliar application of zinc sulphate on rice and reported significant increases in yield in several experiments with calcareous soil but only in one experiment with neutral or non-calcareous soil. Significant increases in yield of rice due to soil application of zinc sulphate to acid soils of Punjab were reported by Kanwar in 1964 and Kanwar and Joshi in 1964. Increase in yield of rice due to soil application of zinc was also reported from Tamil Nadu by Karunakar in 1952 and other States.

Significant increases were also obtained in acid soil under pot-culture conditions. In 1964, Singh and Jain obtained increased (16.1 and 19.5 per cent) grain yield of rice by foliar application of 1.25 and 2.53 kg|ha respectively of zinc as zinc sulphate. Subbarao *et al.* in 1959 reported a high response of cane yield to the application of $ZnSO_4$ at the rate of 5.6 kg|ha to the furrows before planting. Kanwar in 1962b observed an increase of 30.4 q|ha of potato tubers over NPK alone by soil application of zinc sulphate at 33.6 kg|ha, whereas there was no response to other micro-elements. An increase of 108 q|ha was also noted in the Kulu district by Kanwar and Joshi in 1964. Gautam *et al.* in 1964 observed that soil application of zinc sulphate (5.6 to 6.7 kg|ha) together with NPK and other micronutrients increased maize yields over that of NPK alone, and that soil application of zinc and other micronutrients was superior to foliar sprays. At Ludhiana, Kanwar *et al.* in 1958–62 and Bhumbla *et al.* in 1963–65 observed significant increases in yield of maize by spraying zinc sulphate. At Palampur, Kanwar and Joshi in 1964 reported that soil application of zinc sulphate increased the yield of maize over NPK alone by 242 kg|ha. In the Kulu district also significant increases were obtained by Pareek and Jain in 1966 by soil application of zinc sulphate. With desert soils of Rajasthan also, soil application of zinc sulphate at the rate of 11.2 and 22.4 kg|ha increased grain yield over NPK alone by 4.2 and 4.11 q/ha respectively. In Rajasthan, Mathur *et al.* in 1959 obtained increased (not significant) yield of barley 83 to 407 kg|ha over the control by soil application of zinc at 5.6, 11.2 and 22.4 kg|ha. Das and Shrivastave in 1965 reported that treating the seeds with zinc sulphate solution (0.04 per cent) increased the yield of barley grain by 11.9 per cent and straw by 12.3 per cent. Beneficial effects on yield of *ragi* were reported by Gopalarao and Govindarajan in 1950 and Govindarajan and Gopalarao in 1951 by application of 5.6 kg|ha zinc sulphate to the reddish-brown sandy loam field at Bangalore. The effect was more pronounced under irrigated conditions. In 1953, Govindarajan also observed increased yield, both under irrigated and non-irrigated conditions, by pre-soaking *ragi* seeds with 1 per cent zinc sulphate solution.

MANGANESE

The visual symptoms of manganese deficiency in different crops are given below.

Oats: The second and third leaves with marginal grey-brown necrotic spots and streaks; spots usually confined to lower half of the leaf, in due course elongating and coalescing, extending across the leaf blade at the distal end of the basal affected part, consequently causing death of the tissue; collapsing of leaf at this point with a sharp kinking back of the tip. Death of green tissue extending upwards and downwards, leaving the leaf tip green and alive, until most of the leaf shrivels, becomes greyish-brown. In severely affected plants tillering is absent, the growing point dies and fresh leaves are no longer formed.

Wheat: Symptoms less marked, pale-green leaves with faint chlorotic streaking and yellowing; interveinal white lesions and streaks in form of whitish-brown bands developing between the veins.

Barely: Leaf becoming pale-green, very light and dark bordered; occasionally, rust-brown spots appearing between the main veins and coalescing on the leaf margin, in the form of necklace-shaped rows in the centre of the leaf. In some cases necrotic spots developing across the middle of the leaf with the distal end falling over as in oats.

Maize: Mesophyll tissue collapsing, producing white strips due to coalescence of chlorotic spots initially formed between the green veins and resulting in a very characteristic striped chlorosis. Later, the tissue in the middle of the chlorotic areas turning brown and becoming necrotic. Dead tissue sometimes falling out of the leaf leaving a number of holes.

Sugarcane: The disease 'Pahela blight' has been ascribed to manganese deficiency; 3rd, 4th and 5th leaves below the youngest unfolded leaf of the cane develop whitish-chlorotic streaks on the leaf blades. Later small reddish spots appear along the length of the white streaks. Plant growth becomes stunted. In case the red spots are numerous enough, reddish-brown streaks are formed along which the leaf surface splits longitudinally.

Grasses: In general grasses not very sensitive to manganese deficiency; leaves developing brownish tips and greyish spots.

Potato: The top parts of the plant chlorotic, leaves turning pale, losing their lustre, being smaller and curled up; numerous necrotic spots appearing along the veins; in acute deficiency much browning and yellowing of plants, especially young leaves.

Tomato: In areas farthest from the major veins the leaf colour turning light green and finally yellow; yellowing gradually extending into larger areas; the veins remaining green and a mottled appearance develops. Necrosis sets in as small pin-points at the centre of the yellow area; little or no blossoming; no fruit formation.

Tobacco: The younger leaves losing colour between the veins; followed by loss of colour in the minutest branches of the veins, giving the leaf a checkered appearance due to the contrast between green veins and the chlorotic tissues. Spots of dead tissue appear scattered over the entire leaf, and these dead tissues may ultimately drop out. Considerable dwarfing and yellowing of the plant occurs.

Spinach: Chlorosis starts in the growing tips and gradually extends throughout the plant. The web of the leaf turns pale-green to golden-yellow. The green colour persists longest along the main veins. Later on, white dead areas may appear between the leaf veins.

Sweet potato: The leaves develop slight chlorosis with the vein network remaining green. In case of a severe deficiency the background lightens to a pale yellowish-green. Younger leaves are affected first. Vine growth becomes somewhat limited. Sweet potato production is reduced but the size is not much influenced.

Cucumber: The web of the leaf becomes yellowish-white, while the regions along the vein and midrib remain green. Stems and leaves are smaller, weaker and slender.

Brassica *crops*: The symptoms first appear as an interveinal chlorotic marbling. Under severe deficiency the entire leaves may be practically bleached, only the veins remaining green (Kale) or some necrotic tissue may develop in the mottled tissue, when it takes on a dull brownish appearance (Savoy cabbage).

Peas: The plants may appear quite healthy or in severe deficiency, may have slightly chlorotic foliage. Young tendrils and internodes at the tops show brownish discolouration. The youngest leaves may fail to expand. Slightly older leaves acquire characteristic mottling due to green veins and yellow interveinal areas. The lower leaves retain green colour. Later, growing tips and younger leaves may die.

The seeds show a very characteristic condition known as 'marsh spot' disease. Small brown specks or larger circular brown areas are seen on the inner flat surfaces of the cotyledons. The areas may become hollowed out in very severe deficiency.

Peanuts: Leaves start yellowing and later on take up bronzed appearance.

Beans: Interveinal chlorosis. In severe cases the entire leaf turns yellow to yellowish-green, and the veins remain green and stand out in marked contrast. The seeds may have 'marsh spot'.

Cotton: Yellowish-grey or reddish-grey leaves with green veins.

Flax: Chlorosis and twisting of top.

Rubber plant: An overall paling with bands of green tissue outlining the midrib and lateral veins. Growth is retarded.

Flowering plants: Chiefly in roses and chrysanthemum and to a lesser extent in *Primula obconica*, *Syringa* and *Gerbera* there occurs a chlorosis of leaves, the veins remaining green. Moreover in lilac, brown spots appear on the leaves.

Coffee: The leaves show a network of green veins on a lighter green background. Symptoms more characteristic on younger leaves. The plants do not produce any flower. The growth of the trees are slightly reduced but there is no leaf dropping.

Onion: Chlorotic streaking of leaves.

Apples: Interveinal chlorosis, which begins near the margins and extends towards the midrib, and finally only the veins remain green. Strongly growing young shoots may be only little affected (difference from iron deficiency).

Pears: The normal green of the leaves may appear slightly faded and somewhat faint interveinal chlorosis develops, beginning near the margin and progressing towards the midrib. The chlorosis is less pronounced than and very distinct from that of iron deficiency.

Plums and peaches: Same as for apple but the chlorosis may be very severe.

Cherries: Leaves show a marked interveinal chlorosis with a very definite pattern, beginning near the margins and progressing towards the midrib.

Raspberries: The leaves may show interveinal chlorosis over a considerable length of cane. With some varieties (e.g., Lloyd George) the V-shaped interveinal chlorotic pattern is very clearly marked but for others it is more diffuse. There may be some difficulty in distinguishing between Fe and Mn deficiencies, though the former is usually restricted to tip sections.

Gooseberries and strawberries: Very resistant, slight interveinal chlorosis under extreme conditions of deficiency.

Citrus: Leaves yellow-green or chlorotic but do not mottle.

Gum or resinous spots occur on either or both sides of the leaves, their number at first being greatest along the base of the midrib. In acute cases leaves abscise prematurely and shoots die-back. Such shoots may show a resinous excrescence or gum-pockets from which gum may be exuded.

Pineapple: Slight yellowing of the plant was noted in later stages (near harvest) but no chlorosis of leaves. Growth, fruit, slip, sucker and root production normal.

Soil conditions influencing availability of manganese. Total manganese in a soil is made up of three forms with widely different solubilities and all of these are not readily taken up by plants. The form which is of prime importance for plants is available or 'active' manganese, which includes soluble and exchangeable bivalent manganese and those forms of manganese oxide which are easily reduced by hydroquinone at pH 7. A moderately active form of manganese consists of those oxides which oxidize hyposulphite at pH 7 and hydroquinone at pH 2, but not at pH 7.

An increase in pH brings about a conversion of bivalent manganese compounds to unavailable manganese oxides. On the contrary, manganese toxicity is rather common at pH 4.5 or lower.

Although it has been repeatedly found that addition of organic matter to soil brings about deficiency symptoms, the role of organic matter in making bivalent manganese unavailable is not clearly understood. There are also reports about the amelioration of manganese deficiency by the addition of organic matter, and this effect is attributed to reduction of manganese oxides to bivalent manganese by the organic matter at high pH.

Nitrate and ammonium fertilizers (and sometimes also phosphatic) have been reported to increase the uptake of manganese. Phosphatic fertilizers as well as lime have been found to suppress the effects of manganese toxicity; heavy liming, however, often leads to manganese deficiency.

Waterlogging increases the available manganese to toxic limits due to anaerobic conditions.

Correction of manganese deficiency and excess. Manganese sulphate is by far the most common form of manganese fertilizer used, although other carriers of manganese have been found to be generally as effective as manganese sulphate. Doses varying from 20–100 kg per hectare have been recommended by various authors; alkaline or organic matter-containing soils may require even larger amounts. Spraying with manganese sulphate has also been recommended, but more than one spray may be necessary.

Spraying is economical since much smaller amount can be employed. The usual range of concentration used is 0.2–0.5 per cent manganese sulphate solution at the rate of 500–1,000 litres per hectare. Manganese chloride solutions ranging from 2–10 per cent in concentration have also been used in correcting manganese deficiency in forest trees.

In fruit trees injection of solid manganese salt (bore-hole method) has often been found useful. It has been reported that for grapes the bore-hole method and spraying were not effective; application of manganese sulphate paste (400 g manganese sulphate, 400 g sugar and 300 g sulphate) on pruning cuts was recommended.

Application of manganese chelates (Mn-EDTA, Mn-HEEDTA, etc.) to soil or as spray has also been reported to be useful.

Manganese toxicity can be corrected by addition of lime to the soil or by spraying iron salts.

Response to manganese under Indian conditions. In 1953, Dastur and Kanwar Singh reported that manganese applied at the rate of 16.8 kg|ha on black cotton soils at Indore significantly increased the yield of seed cotton. An average increase of 30 per cent in grain yield and grain protein of wheat was obtained at Delhi, over a period of three years, from soil application at the rate of 11.2 kg|ha and spray application at the rate of 0.9 kg|ha. Gosh *et al.* in 1964 observed significant increase in yield of potatoes by soil application of (22.4 kg|ha) of manganese. In Andhra Pradesh, Krishnamurty in 1959 noted drying of leaves from apex downwards, chlorosis progressing from leaf margins inwards and premature death of tillers in rice with toxic levels of manganese. He attributed the chlorosis of rice to manganese toxicity. Kanwar *et al.* in 1958–62 and Bhumbla *et al.* in 1963–65 obtained an increase in yield of rice with foliar application of manganese in 2 out of 7 experiments on calcareous soils, but little or no response in neutral and non-calcareous or acid soils. Foliar applications of manganese significantly increased the yield of wheat grain in 6 out of 14 trials in calcareous soils and in only 3 out of 6 trials in acid soils. Mathur *et al.* in 1959 observed increased yield of wheat by soil application of manganese. In 1964, Koraddi and Seth observed that soil application of manganese (9.84 kg|ha) increased the yield of wheat grain by 23.7 per cent and foliar application (2.46 kg|ha) by 17.8 per cent over NPK treatment under Delhi conditions. In 1965, Das and Srivastava reported that seed treatment with manganese delayed maturity but increased the yield of straw and grain in barley. Kanwar *et al.* in 1958–62 and Bhumbla *et al.* in 1963–65 obtained increased yield of maize by foliar application of manganese sulphate. Increased yields of maize by soil application of manganese were also obtained by Kanwar and Joshi in 1964 and Pareek and Jain in 1965 at Palampur and Rajasthan, respectively, whereas Ghosh *et al.* in 1964 observed no such response at Delhi. In 1965, Jogi and Ahuja (1965) noted that soil application alone of manganese and in combination with all micronutrients increased the yield by 25 per cent and 16.6 per cent respectively, in hybrid maize at Solan. Joshi in 1965b, in Maharashtra, and Datta and Bains in 1959, at Delhi, found that *jowar* responded well to application of manganese. In Rajasthan, Jain and Mehta in 1965 obtained a slight increase in yield of gram (8.0 to 40.3 kg|ha) over control by soil application of 5.6 and 11.2 kg|ha of manganese sulphate to the sandy soils. At the Indian Agricultural Research Institute, grain did not respond consistently to manganese application.

COPPER

Deficiency of copper causes a number of irregularities in plant growth, as described below.

Maize: Youngest leaves become light yellowish-green near the base of the leaf and tips necrotic. When deficiency is less severe, and plants are 1.2–2.4 m tall, necrosis appears along the margins of the upper leaves, usually near the base and sometimes extending to the tip. (Similar to K deficiency, but narrower, particularly at the leaf tip, and appear only on upper leaves).

Wheat: Growth is restricted in copper-free cultures for some time before specific deficiency symptoms develop. Deficient plants gradually become pale-green (than normal) and show limpness or lack of turgor in the emerging leaves. Older leaves remain green and healthy but bend back sharply close to the ligule. Later emerging leaves fail to unroll normally, turn yellow at the tips and die. Growth of tiller ceases. The older leaves die and dry out to a bleached greyish colour.

Tomato: Growth of shoots is stunted and root development is exceedingly poor. Other symptoms seen are dark bluish-green colour of foliage, leaves curling upward and inward and reduction in size of leaves, absence of flower formation, development of mottled chlorosis of leaves and a lack of firmness in leaves and stems. There is a permanent wilting of the entire top of the plant. At later stages necrotic areas may appear in the leaf tissue.

Onion: Scales are abnormally thin and are of pale-yellow colour. Cu-deficient onions lack solidity and firmness.

Egg-plant—Plants are severely stunted and chlorotic with green spots on the leaves, and marked yellowing and browning at the leaf tips.

Tobacco: The deficiency symptoms start as dull greyish-brown 'greasy' looking spots, concentric in formation, located between the veins; spots vary in size from 3.1–12.7 mm in diameter. They dry out from the centre, turning brown while the surrounding tissue is yellowish-green. The disorder usually shows up first towards the leaf tip, but eventually all the portions of the leaf may be involved. The spots tend to spread and coalesce to form large irregular patches which dry out to a warm brown colour in which the original spotting can be seen as a marbling effect. There is a warm chestnut-brown discolouration like air-dried barley.

The upper leaves are unable to retain turgor or rigidity so that they wilt badly. When copper deficiency becomes evident during the flowering stage, the seed stalk does not stand erect and the amount of seed is reduced.

Flax and linseed: In the beginning growth is normal for about a month. Afterwards growth is retarded, internodes become short, giving the top a somewhat rosetted appearance. New leaves are smaller and more pale-green as compared to control. They become puckered, slightly inrolled along the edges and very twisted. The stems of plants are also twisted. Later the leaves in the middle portion of the stem develop a dark greyish-green, semi-transparent discolouration at the tips. These leaves soon drop off and wither, and die from the tips downwards. The lowest leaves remain normal. Secondary shoots are sent from the bottom but soon become chlorotic with small twisted leaves. Finally growth ceases and plants start dying. Blooming is inferior and seed capsule-formation lesser.

Peas: The first noticeable symptom is the limpness of the top few cm of the main stem; considerable dropping occurs, and it is unable to support itself in an erect position. Apart from this, vegetative growth appears normal and no characteristic leaf symptoms are observed. Only a few flowers are formed, no seed is formed and the plants die earlier than those receiving copper. Under field conditions the decreased seed production is the most important feature of the disease in peas.

Lucerne: Petioles of newly-formed leaves shows a peculiar epinastic curvature. The petioles of newly-formed leaves curve downwards and the leaflets fold backwards along the petiole instead of opening out. Shortly afterwards the leaves wither and die, and the tips of stems cease growth.

Pepper: Plants are severely stunted and become chlorotic with the leaves cupped, crinkled and twisted.

Cabbage: Plants are chlorotic and stunted, and do not attain enough growth to produce heads.

Carrots: Growth is severely checked. Plants are highly stunted with very small roots.

Citrus: First signs usually develop with the flush of new growth. The leaves frequently become abnormally large and dark-green, while new branches make angular or distorted growth and sometimes develop an S-shaped curvature. The bark of the terminal branches becomes stained with a dark-brown, gum-like material and the shoots usually turn yellow and die. Blister-like gum pockets between the wood and the bark and multiple bud formation are also characteristic of the disease. In some instances the multiple buds develop into branches giving a bushy rosette-like growth. The fruit is affected, the skin being marked with irregular gum-soaked areas which cause hardening and cracking. The affected fruit frequently splits and drops. When the disease is severe, dieback of the tree may be so extensive that little fruit is left.

The symptoms differ somewhat between different root-stocks (Hambidge, 1949).

Apple: Growth is retarded with marked rosetting and dieback of leading branches.

Prunus *spp.*: Growth is restricted, and the trees are small and under-developed. Vigorous spring growth is produced, but after a time the terminal buds wither and fall out and the terminal leaves turn yellowish. Later growth, if formed, dies back. Eruption in bark and swollen multiple buds occur.

Pears: Tips and apical leaves become badly scorched resulting in dieback. There is no rosetting. Affected trees bear practically no fruit.

Plums, peaches and apricots: The symptoms are yellowing of leaves, the areas between the veins being very pale to bright yellow. In extreme cases smaller veins also turn yellow. Serious rosetting with a resultant cessation of terminal growth, formation of multiple buds and eventual dieback of the branches from the tips.

Soil conditions and availability of copper. The total amount of copper in agricultural soils varies from 1–50 ppm, but lower ranges may be found in weathered, leached and acid soils. The total amount of copper present in a particular soil is no indication of the amount available to the plant in that soil. Three forms of copper can be distinguished, namely, (*a*) water-soluble, (*b*) absorbed, and (*c*) fixed. Mitchell *et al.* (1957) found some correlation between the copper content of clover and total soil copper, acetic acid-soluble copper and EDTA-extractable copper, but they considered only the latter to be satisfactory for the diagnosis of copper-deficient soils.

A decrease in acidity generally reduces the availability of copper. There are, however, reports that in soils with high organic matter content, the copper content of the plant tissues was independent of soil pH and varied according to the copper content of the soil. It is perhaps due to this reason that many highly organic soils can be made productive only after large additions of copper. Copper deficiency is relatively more common in gravelly or sandy soils than in those with a higher content of clay. It appears that a major part of the exchangeable copper occurs in the clay fraction and not in the organic matter.

Control measures for copper deficiency. Copper sulphate is commonly used for the correction of deficiency of copper. The doses of soil application vary according to the crop and severity of the deficiency. The time of application has often been found to influence the utility of copper dressing. Spraying of copper sulphate has also been found to prove beneficial. Available reports on copper toxicity show that it occurred due to injudicious application of copper to soil or as spray and great caution should, therefore, be exercised in its application for amending the deficiency.

Response to copper under Indian conditions. Copper deficiency adversely affects grain setting and, as such, one may find normal vegetative growth without any deficiency symptoms. In such cases the yield is depressed. On the other hand application of copper sulphate has resulted in increased yield.

In 1964, Randhawa and Kanwar reported that Punjab soils contained high reserves of copper. Agrawal and Motiramani in 1966 studied the copper content of Madhya Pradesh soils and observed that 1 ppm is the critical level for available copper and it formed 8 to 10 per cent of total copper.

In 1952, Joshi and Joshi obtained 35–80 per cent increase in the yield of paddy by application of copper sulphate to soil at the rate of 1.12 kg|ha in several places in Konkan and in Maharashtra. Abichandani in 1955 did not, however, find any beneficial effect of copper sulphate application on paddy at Cuttack. Kanwar *et al.* in 1958–62 and Bhumbla *et al.* in 1963–65 observed significant increases in yield of rice by foliar application of copper sulphate in one experiment out of seven in calcareous soils, but little increase in neutral and non-calcareous soils. With acid soils the response to soil application was, however, significant. Sadaphal and Das in 1956 obtained about 15 per cent increase in yield of wheat, at Delhi, by soil application of 5.6 kg|ha of copper or spray application of 1.12 kg|ha of copper. Mathur *et al.* in 1959 did not, however, find any significant beneficial effect of 11.2 kg|ha copper sulphate on wheat in Rajasthan. Kanwar *et al.* in 1958–62 and Bhumbla *et al.* in 1963–65 observed significant increases in yield of wheat in 1 out of 14 experiments in calcareous soils by

foliar application of copper sulphate. In 1964, Koraddi and Seth reported that soil application of copper (5.08 kg|ha) increased the yield of wheat grain by 16.9 per cent and foliar application of copper (1.27 kg|ha) by 12.7 per cent over that from the NPK-treated controls. Dastur and Kanwar Singh in 1953 reported a beneficial effect on cotton in the black cotton soils at Indore. Kamalkantan *et al.* in 1966 observed that soil application of copper increased the yield of cotton, Jogi and Ahuja in 1965 observed increased yield of hybrid maize with application of copper in combination with NPK. In Rajasthan, Pareek and Jain in 1966 also observed increased yield of maize grain over NPK by soil application of copper (5.6, 11.2 and 22.5 kg|ha). In Maharashtra, Joshi in 1956b got significant increases in yield of *jowar* by application of copper. In Rajasthan, Mathur *et al.* in 1959 obtained increase in the yield of barely 239, 156, 287 kg|ha over the control by soil application of 5.6, 11.2 and 22.4 kg|ha of copper sulphate respectively. In 1965, Das and Shrivastava reported that treating seeds with 0.03 per cent copper sulphate solution increased the yield of grain and straw of barley. Raheja *et al.* in 1959 observed a significant increase in yield (91.4 per cent) of gram by treatment with copper in combination with zinc and manganese at Vijayapur (Mahsana). In Rajasthan, Mathur *et al.* in 1959 got slight increases in yield of gram by 21.2, 82.9, 147.8, kg|ha over control by soil application of (5.6, 11.2 and 22.4 kg|ha) of copper sulphate respectively. In 1965, Radha noted a reduction in leaf-rot and increase in yield of coconut by spraying copper sulphate for four times on the palms.

IRON

Visual symptoms due to iron deficiency on some important crops are given below:

Cereals: Plants are rather resistant. Young plants are markedly chlorotic. The tops of the plants and leaf tips die.

Grain sorghums: Plants slightly affected have green leaves with yellow stripes; severely affected plants have leaves entirely yellow with white margins and tips.

Tomato: Leaves near tips of plants show chlorotic mottling, the chlorosis being most pronounced near the midrib and towards the bases of the leaflets. Little necrosis or drying of leaf tissues may occur.

Potato: Plants grown in water culture show slight chlorosis of young leaves rather regularly spread over the leaf-blade. The points and margins of leaflets keep their green colour longest. Discoloured tissues become clear pale-yellow and in extreme cases almost pure white. Chlorotic tissue is curved in an upward direction. Leaves developed before appearance of symptoms remain normal green. These symptoms have not been reported so far from fields, where the plants are quite resistant.

Brassica crops: Chlorotic 'marbling' of leaves, and occasionally leaves are completely bleached.

Apples, pears, plums and cherries: Interveinal chlorosis with darker green veins in the younger leaves at the tips of shoots. In severe examples shoot tips die and the dieback may extend downward into the larger branches.

Citrus: In mild cases the leaf veins are more dark–green than interveinal areas. In more advanced stages the interveinal areas are yellow and eventually the entire leaf may become ivory coloured. In severe cases trees become partially defoliated, causing dieback. The fruit fails to develop colour properly, production is reduced and in many cases the trees die. In grape fruit, vines are small and very fragile and show a brown impregnation when older. Under acute deficiency the fruit is small, hard, coarse, light in colour and somewhat mis-shapen, especially in lemons.

Influence of soil conditions on the availability of iron. Iron deficiency has been reported from acid (*e.g.*, Florida) as well as alkaline soils but it is more common in the latter. It has been suggested that chlorosis in acid soils may be caused by a higher concentration of heavy metals relative to that of iron. The most widespread incidence of iron deficiency in plants, namely, lime-induced chlorosis, occurs in alkaline-calcareous soils. How this chlorosis is actually caused is still a matter of controversy; presence of bicarbonate and manganese, high application of phosphatic fertilizers, and poor drainage are supposed to be the factors involved.

Measures for correcting iron deficiency. For a long time the iron deficiency has been the most difficult of all nutritional disorders to correct; soil treatment has usually proved ineffective and spraying of iron sulphate or iron chloride has not given uniform results. Injection of iron salts into stems has proved effective in some cases. In recent years iron-chelates have been found to be more effective. These can be used for soil application and also as sprays. Caution must be exercised in choosing the dosage, as excess of it may cause severe burning. Proper doses for different soils are still to be worked out. In soil application chelates should be thoroughly watered into the soil and then normal irrigation procedure should be followed. Evergreen plants can be treated successfully at any time of the year, but application during the active growing season would give better results. For deciduous plants the treatment should be given during the early part of the growing season.

Iron-EDTA is considered more useful for acid soils, and iron-EDTA-OH, iron-DTPA and iron-HEEDTA for alkaline and high lime soils.

BORON

The symptoms caused by boron deficiency on important crops are described here.

Citrus: Affected plants show downward curling of leaves, corky and splitted midribs, multiple bud formation, spliting of bark, oozing of gum, dieback of apical growing point, reduced flowering and decay of roots.

Cauliflower: Floral head shows rust-brown discolouration, and the leaves are discoloured with yellow and red margins. Water discolourations later passing over into necrosis occur on the midribs, particularly of the young leaves.

Cabbage: The symptoms are dwarfing and distortion of leaves with concentric water-soaked areas, surface browning, bad flavour and interveinal breakdown in pith.

Lucerne: The foliage has a faded brown or greyish-yellow discolouration beginning from the top and the margins of the leaflets. The veins remain green for longer period than the rest of the lamina. The yellow discolouration is frequently followed by anthocyan-red discolourations of the leaf margins, particularly the denticulations. The top leaflets are rounder and wider. The plants remain small and thick-set.

Potato: The growing point dies off and the foliage becomes thick and brittle. The leaf margins curl upwards and the plant has a squat appearance. The leaf stalks break off easily, especially in the older leaves. The tubers usually have a rough and cracked surface, and are smaller than usual. The tuber developes a local or universal brown discolouration of the vascular ring, which is generally greatest at the navel end of the tubers. In severely affected tubers the part inside the ring of vascular bundles often has a glossy appearance.

Tomato: The plant assumes bushy appearance with a blackened appearance at the growing point. The seedling and the true leaves turn to a distinctly purple colour. The stems become stunted and the terminal shoot curls inwards, yellows and dies. Stems and petioles become brittle; the roots show extremely poor growth and become yellow or brown in colour. The fruit is frequently covered with darkened and dried areas.

Radish: Leaves turn light bluish-green and the petioles are brittle and curled down; roots remain light in colour, round, elongated and severely cracked. Apical buds and phloem develop necrosis.

Tobacco: Plants develop 'top-sickness', light green colour of the bud leaves, distortion of foliage during expansion, twisted top growth and dieback of terminal buds. Growth remains stunted and flowering is inhibited. Injury is more pronounced in vigorously growing plants.

Pea: Short, thick roots with enlarged apices and suppressed growth of secondary roots are the symptoms in this plant.

Broad bean: Shoot apex withers and internal tissue disorganizes, particularly in roots.

Maize: Chlorosis of tissue between veins of old leaves, translucent stripes in the longitudinal direction of the leaves, failure of young leaves to unroll, subnormal development of lamina, disturbed meristematic growth, partial sterility and poor cob-formation are the symptoms. Root tips become swollen and stunted followed by internal breakdown and disorganization.

Wheat: Tillering is abnormal with no ears, or ears are badly damaged or are sterile.

Barley: Ear-formation is checked.

Sugarcane: There is depression in growth and distortion and chlorosis of leaves. Definite stem and leaf lesions are formed.

Cotton: Necrosis of the apex of stems, roots, deformation of young leaves and stripping of leaf stalks take place. Deficiency may increase vegetative development expressed in dry weight of the total dry matter.

Grape: Early symptoms are diffuse yellowing or chlorosis of the younger leaves, brownish water-soaked areas developing in the apical tendrils and cupping of the third or fourth leaf from the shoot tip. The exact order of appearance of these symptoms varies with the variety. Apical internodes are shortened and all parts exhibit abnormal rigidity and brittleness. Young leaves are misshapen and malformed.

Apple: Death of new shoot is followed by appearance of side shoots which too die later on. Well-defined brown spots appear on the bark which were originally green; when close to the surface the patches look like dark glossy spots. Afterwards the patches become brown and dry to a sponge-tough consistency. Malformation and splits in the fruit occur.

Peach: Twigs dieback from their tips but tend to develop new shoots in abnormal number behind the injured terminals. Young and immature leaves fail to attain normal size but become thick, wrinkled and otherwise mis-shapen and brittle.

Plum: Brown, sunken areas in the flesh of the fruit, chlorosis and twisting of young leaves, necrotic spots on older leaves, and short and little internodes are the symptoms.

Pear: The plants show corking of fruits and formation of pitted branches giving a typical measle-type appearance.

Flax: Root development is poor, death of leaves and decay of shoot apices take place.

Sweet potato: Internodes become shortened and terminal growth is restricted. Petioles are curved and terminals stunted and distorted. Moderately affected tubers are mis-shapen and the skin becomes thick and leathery. Other malformations are dumb-bell-shaped, lopsided and spindle-shaped tubers. Severely affected tubers have cankers covered with hardened dark exudate. Internal areas are necrotic throughout the fleshy part of the tuber but more so in the cambial zone near the periphery.

Onion: Plants are stunted and distorted in appearance. Leaf colour varies from dark grey-green to deep blue-green; the youngest leaves develop conspicuous yellow and green mottling and shrunken areas, followed by ladder-like transverse cracks on the upper side of basal leaves. Leaves are stiff and brittle.

Oil palms: Characteristic 'hook-leaf' distortion of the foliage appears leading in severe cases to reduction in size of leaves.

Tissue analysis. The boron content of different plant species has been found to vary from a minimum of 0.2–2.00 ppm. A survey of the available records reveals that deficiency levels are of the order of 0.2–5 ppm, though some plants may show values higher than 5 ppm and still manifest the deficiency symptoms. The sufficiency level probably varies from 1–40 ppm. Boron toxicity is manifested in species having concentrations varying from 40–200 ppm or above.

Soil conditions influencing availability of boron. Of the three categories of boron, namely, total boron, acid-soluble boron, and water-soluble boron, it is the last that exhibits the highest correlation with the incidence of disease. Boron is least deficient in the upper 7 cm of the soil and the rate of movement depends largely on soil texture; boron moves to a depth of 60 cm in light-textured soils and approximately to 30 cm in heavy soils.

Deficiency effects differ with soil type. Old, leached, peaty soils or those derived from igneous rocks are deficient in boron. The medium-textured sandy soils have a lower optimum range of boron than clay.

The soil reaction also governs the availability of boron. Deficiency symptoms occur at pH 7 and become more severe at higher pH. Between pH 4.1 and 11.5 boron is hardly fixed by soil; uptake of this element by plants is also not altered over a wide range of soil pH. However, in alkaline soils, its availability is influenced largely by pH. In acid soils boron in mineral form is leached out, while the organic form of boron may become fixed in a stable and unavailable form if lime is applied.

Interrelated with the influence of pH is the effect of organic matter. It has been shown that available boron decreased with increasing acidity, probably due to the fact that organic matter also decreased with increasing acidity. The effect of organic matter on these soils is to keep boron in a more available form. The final effect of organic matter on the availability of boron is, however, not as great as that of pH; this is particularly true where the pH is above 7.

Another factor that contributes to the availability of boron in some soils is that of leaching. It is observed that 63.94 per cent of boron may be leached out, depending on the soil texture. Further, it has also been seen that leaching is a relatively more important factor in acid soils than in alkaline soils.

Cultural practices and boron availability. Liming the soil leads to an increase in the boron deficiency. Whether this is due to a change in the availability of boron in the soil or whether changes occur in the plant is a disputable problem, although both may be operating simultaneously.

Liming is not the only factor influencing boron deficiency. A potash dressing may favour the occurrence of boron deficiency.

In farming practice dry weather is found to favour the occurrence of boron deficiency. Whether this is due to fixation of boron in the soil or due to the plant's inability to absorb the nutrient without moisture is controversial.

Control of boron deficiency. Boron deficiency has been remedied generally by soil application and the salt which has been usually found beneficial is borax, though boric acid has also been used by a few workers. Other methods of overcoming boron malnutrition include spraying the plants and pre-soaking of the seeds to be sown.

The boron toxicity is not an outstanding problem as, wherever experienced, it has been successfully overcome by liming the soils.

Crop	Date	Mode of application
	BORAX	
Beet	25–30 kg|ha	Soil application
Cauliflower	4 g| m^2	" "
Potato	5 kg|ha at pH 6, 10 kg at pH 6.0–6.5, 15 kg at pH 6.5–7.0, 20 kg on calcareous soils	" "
Peanuts	5.6 kg|ha	" "
Lucerne	400 kg|ha	" "
Plum	0.22 kg|tree	" "
Apple	16–45 kg|tree	In a ring around the tree
Pears	1.3|27|450 litres of water	Autumn spray of plants
Anjou pears	52–416 ppm of water	Foliar spray
Cotton	5.6–11.2 kg|ha	Soil application
Vines	100 kg|ha	" "
"	0.5 per cent	Foliar spray
	BORIC ACID	
Citrus	1 g|m^2	Soil application
Potato	200 kg|ha of lime ammonium nitrate containing 2.5 per cent boric acid	" "

The doses of borax applied for correction of boron deficiency vary for the different species. These are given at page 185.

Response to boron under Indian conditions. In 1953, Dastur and Kanwar Singh obtained an increase in the yield of seed cotton in the black cotton soil at Indore by application of borax at the rate of 19 kg|ha. Kanwar *et al.* in 1958–62 and Bhumbla *et al.* in 1963–65 obtained a significant increase in yield of rice in one out of seven experiments in calcareous soils by foliar application of boron, but not in neutral and non-calcareous and acid soils; the yield of wheat was increased in 1 out of 15 experiments in calcareous soils and in 3 out of 6 in acid soils. Mathur *et al.* in 1959 observed non-significant increases in yield of barley and wheat by soil application of 5.6, 11.2 and 22.4 kg|ha boron to sandy soils of Rajasthan. Joshi in 1956a observed that response of wheat to boron increased when it was applied in combination with organic matter. The response of wheat crop to application of boron has, however, varied in different areas. In 1956, Joshi obtained an increase yield by the application of boron, whereas no response was obtained at Niphad (Maharashtra) and at Durgapur (Rajasthan) in the agronomic trials with fertilizers. It is interesting to note that at the Indian Agricultural Research Institute, application of borax at the rate of 22.4 kg|ha increased the yield by 336|ha (average of four seasons). As the cost of borax is Rs 1.65 kg, the application is economical (Malkani and Asana, unpublished). Beneficial effect of application of boron to sugarcane was reported by Lal and Srivastava in 1948, Mohan Rao *et al.* in 1956 and De and Singh in 1960. Tillering and juice quality in sugaracane have also been reported to improve as a result of boron sprays. Application of boron to soil in furrows before planting and also foliar application were reported to increase the yield of sugarcane. Singh in 1963 obtained a significant increase in yield and better seed-set in *Brassica* species by foliar application of 500 ppm boron. Ghosh *et al.* in 1964 obtained a 20.9 per cent increase in yield of potatoes by application of boron at 5.6 kg|ha in the Middle Block fields but no response was noted in the Main Block fields at the Indian Agricultural Research Institute, New Delhi. In 1963, Jain and Mehta observed that application of 5.6 and 11.2 kg|ha of boron depressed the yield of gram by 12.0 and 53.4 kg|ha respectively, in sandy soils in Rajasthan. Mandal *et al.* in 1956 got 100 per cent increase in yield of maize by the application of borax at the rate of 22.5 kg|ha as compared with sandy loam soils of Islampur in Bihar State. Pareek and Jain in 1965 observed a slight increase in the yield of maize by soil application of 5.6, 11.2, 22.5 kg|ha of boron. Gandhi and Mehta in 1958, and Tamboli and Dube in 1964 did not observe any beneficial effect on the yield of berseem. Datta and Gurubasava Raj in 1955 found at Delhi that application of 5.6 kg|ha of borax significantly increased the yield of berseem from 821 q|ha (in control) to 900 q|ha, besides, the number as well as the weight of the nodules increased. Further work conducted at the I.A.R.I, New Delhi, has shown that application of 5.6 kg|ha of boron increased the yield of green fodder berseem by 1120 kg|ha (over 943 kg of control), and of seed by 33.6 kg|ha (over 246 kg|ha of control). Application of boron to the soil was more effective than as foliar spray.

From the observations reported above, it appears that application of boron to the soil has proved beneficial in a large number of cases. Great caution must be exercised in its use, as the range between the optimum and the toxic levels of boron in soil is very narrow and repeated application may make the soil toxic.

MOLYBDENUM

The deficiency symptoms in different plants are described below:

Oats (Avena sativa): Erect plants with pale-green leaves. Slight interveinal chlorosis accompanied by grey interveinal lesions which later become brown, or orange-red flecks with leaf tip scorching. Growth and grain formation decreased.

Wheat (Triticum aestivum): Chlorosis. Many glumes empty. Ripening delayed and shrivelled kernels.

Barely (Hordeum vulgare): Growth is drooping and stems are limp. Foliage is dull pale-green. Leaf tips and margins develop grey interveinal necrotic areas and scorch rapidly. Middle-aged leaves most sensitive. Leaf tip scorch extends irregularly, leaving isolated areas of initially unaffected tissue. Youngest leaves remain rolled and chlorotic with a constriction near the apex. Stems collapse after death of younger leaves before emergence. Flowering and grain formation are suppressed.

Maize (Zea mays): Plants stunted; older leaves with a blighted appearance or 'white' scorched condition. General yellowing of plants.

Tomato (Lycopersicon esculentum): Cotyledons remain green for several weeks. Older leaves are pale with diffuse marginal and interveinal bright yellow mottling. Leaf margins curl upwards and leaflets appear rolled. Pale-brown scorching begins at the tip of the apical leaflet of the oldest leaf and spreads inward. The distal lateral leaflets are next involved until the whole leaf is totally withered. Leaves are affected in succession, and the apical leaflet scorch appears when the first or second lateral leaflets of the next older leaf are partly withered. Flowering and fruiting suppressed. Plants eventually die.

Potato (Solanum tuberosum): Severity of symptoms dependent on tuber reserves of Mo. Symptoms usually appear in second cycle (plants raised from tubers of previous deficiency treatment). Partly or newly expanded leaves turn pale and show golden-yellow chlorosis with occasional dull white mottling. Chlorotic areas irregular and diffuse but leaf margins often dark-green. Leaf margins curl upwards, with irregular necrosis followed by general withering. Young leaflets and flowers turn brown and wither before opening, followed by the death of stem's growing point. The symptoms recur in lateral branches.

In the third deficiency cycle plants are initially pale-green. Apical leaflets of the lower leaves appear larger than those on normal plants and show marked marginal cupping, pale yellow-green interveinal chlorosis and marginal yellowing. Margins and interveinal areas develop brown scorch, successive leaves wither and fall. Some leaves show purple spots around leaflet margins.

Tobacco (Nicotiana tabacum): First symptoms are crinkling and mottling of mid-stem leaves. These curl or get twisted and develop small, necrotic interveinal areas, which coalesce. Leaves wither from margins and become bleached. Symptoms spread to younger and older leaves. Stem height decreases and flowering is delayed.

Spinach (Spinacea oleracea *var.* crassa): Chlorosis and severe necrosis of successive leaves followed by death of plants. Mulder (1954) reported pale-yellow leaves, marginal cupping and necrosis.

Cauliflower (Brassica oleracea *var.* botrytis): In young plants leaves are cupped and show chlorotic mottling. Tips develop dead patches. Cotyledons remain dark-green. Marginal limpness, wilting and scorching of leaves occur followed by leaf withering, occasionally preceded by wilting of petioles. Later on there is restricted development of leaf laminae, leaving only bare midribs, producing characteristic 'whiptail' condition. Growing point eventually dies (*see also* Hewitt, 1956).

Savoy cabbage (Brassica oleracea *var.* bullata-subauda): Pronounced leaf-cupping and membranous water–soaked margins. Veins may be purple tinted and the general colour is olive-green. Leaf angles are wide, no 'hearting', and lateral buds grow out. When secondary symptoms occur, young leaves become brown, necrotic and malformed on expansion at the margins. Rudimentary leaves turn brown and shrivel, and death of growing point follows brown exudation.

Cucurbits: Stunted plants, yellowish-green leaves; later upcurled leaf margins die off. Chlorosis and cupping in a narrow band along the margin.

Flax (Linum usitatissimum): Old leaves fade and wither. Young leaves are yellow-green and later brown at the tip. Flowering is decreased and pedicels wilt about 3 cm behind the flower bud.

Carrot (Daucus carota): Older foliage pale yellow-green. Leaf segments scorch at tips. Leaves wither and collapse.

Roselle (Hibiscus sabdariffa): Collapse of massive central portion of flower.

Radish (Raphanus sativus): Plants pale-green with bright yellow interveinal mottling of the older leaves. Cotyledons are large and remain green for five to six weeks. Leaf margins markedly cupped. Fluid exudes on the leaf surface and water-soaked areas appear. Margins wilt, inroll and wither. Leaves wither completely except for petioles. Symptoms progress from oldest to youngest leaves until plants die. Flowers die before opening.

Lucerne or alfalfa (Medicago sativa): Foliage dull pale-green. Leaf margins appear grey, limp and curled. Interveinal leaf tip necrosis is followed by rapid bleaching to white scorch. Leaves wither completely and petioles collapse. Symptoms develop mainly in 'mid-stem' or in younger leaves. Mulder (1954) found more numerous, slender, yellow nodules instead of larger red ones.

Red clover and alsike (Trifolium pratense and T. hybridum): Foliage pale or dull grey-green. Margins of older leaves fade, curl inward, become limp and develop red-brown or pale-brown scorch with interveinal necrosis. Petioles wilt and leaflets wither. Warington (1950) observed a blue tint prior to scorching in red clover.

Citrus: 'Yellow spot' disease. Symptoms first appear in early spring as water-soaked areas in leaves. These areas develop in summer in large interveinal yellow spots with green colour on the lower surface.

Grape fruit: 'Yellow spot' disease. Affected areas of leaf become brown and gummy, and eventually die. Trees usually shed their leaves and produce little fruit.

Pea (Pisum sativum): Plants grown from seed raised through two generations of Mo deficiency are dwarfed and pale in 15 days. Old leaves wilt suddenly, curl up, scorch at margins and finally wither completely. Plants wither or may produce a weak basal shoot. Flowering is totally suppressed.

Dwarf French bean (Phaseolus vulgaris): Plants have large pale-green leaves that become mottled interveinally, and rapidly develop large irregular interveinal pale-brown scorched areas. Leaf margins wilt and leaves wither and fall. Prophylls are chlorotic, become scorched or necrotic and wither. Flowering is suppressed.

Climbing French or runner bean (Phaseolus multiflorus *or* coccineus): Leaves tend to be small, uniformly pale yellow-green or yellow and finally bleached with scorched upcurled margins. Oldest leaves are affected first and wither before falling. Stem elongation and flower and seed production suppressed. Plants wither.

Broad bean (Vicia faba): Lower leaves pale, margins and interveinal areas become grey and wilted or collapsed. Dark-brown or black scorching rapidly follows, while blackening appears in younger leaves. Stems become almost totally defoliated. Flowering and seed production are almost completely suppressed.

Lemon (Citrus limonia): Leaves rough in texture, possibly due to enlarged oil glands. Diffuse rounded or oval mottled areas especially in the marginal and apical regions. These become necrotic and dry out to an irregular pale-brown marginal or interveinal scorch. Margins curled upward to produce an upward pointed outline. Leaves fall prematurely, and axillary branches are numerous.

Rubber (Hevea *sp.*): Seedlings reduced in height and girth. Marginal or tip scorch appears in mid-stem and upper laminae.

Concord grapes: Chlorosis of terminal leaves followed by necrosis in the basal leaves.

Apples: In seedlings of variety 'Rome Beauty' uniform chlorosis is observed. Scorching of tips and margins of older leaves with eventual down-cupping and a general reduction of vigour and growth.

Soil conditions related to availability of molybdenum. Molybdenum is widely distributed in soils in low amounts and occurs in the soil in: (*a*) unavailable form (held within the crystal lattice of primary and secondary minerals); (*b*) conditionally available form (as MoO_4 anion in clay minerals and available to a greater or lesser degree depending on pH and probably phosphate status); (*c*) inorganic matter (likely to be in a continual state of circulation through mineral breakdown); and (*d*) water-soluble form but in very low quantities and may assume importance only under alkaline conditions.

The availability of soil molybdenum to plants depends upon soil pH, aeration and level of phosphorus, manganese and other elements. Molybdenum uptake by plants has often been reported to be favoured by an alkaline soil reaction as compared to an acidic one. Molybdenum deficiency is often associated with acid soils because it becomes less soluble as pH falls. Well-limed or naturally neutral soils may also produce molybdenum-deficient crops due to depletion of available molybdenum by cropping or leaching.

There is evidence to show that phosphorus and potassium deficiencies restrict the response to molybdenum, while heavy applications of manganese sulphate or ammonium sulphate may bring about molybdenum deficiency in the plants. The availability of molybdenum is also affected adversely by the presence of high amounts of iron in a soil.

Heavy cropping might be expected to induce molybdenum deficiency, especially in nodulated legumes, by lowering the level of molybdenum and nitrogen. It is perhaps due to this reason that the greatest response to molybdenum occurred where heavy cropping had been practised and also where the land had been eroded to the sub-soil.

Plant species also differ widely in their capability of quantitative uptake of molybdenum from the soil; legumes and crucifers, for instance, have a high molybdenum content as compared to plants of other families.

Molybdenum toxicity usually occurs in alkaline soils, some organic soils and some 'young' soils but a more critical study of factors affecting molybdenum uptake is essential. Most of the instances reported are of accumulation of molybdenum in forage plants in concentrations toxic to animals. Application of lime to soils high in molybdenum content may also induce molybdenum toxicity. Not much work has been done for the control of molybdenum toxicity, but lowering soil pH, application of ammonium sulphate and composting loam with peat have been reported to be helpful.

Measures for correcting molybdenum deficiency. Sodium molybdate, ammonium molybdate, or the less soluble molybdenum tri-oxide are the suitable forms and appear to be needed at about the same level of application. Recently the Climax Molybdenum Co., New York, have developed a preparation 'Moly-Gro', which is suitable for seed treatment and is claimed to suffice for the needs of the whole plant. It has also been reported that for oats and peas molybdenum glass and frits are more effective than soluble salts. The use of complex forms of molybdenum has been suggested for more acidic conditions, where molybdenum is likely to be fixed easily.

Both soil and spray applications of molybdenum have been used. Molybdenum salt, at the rate of 0.14 kg of molybdenum per hectare, has generally proved effective. Higher levels (up to 4.48 kg|ha of sodium molybdate) have been reported to be needed for cauliflower, alfalfa, lettuce, beet and rye. For soil application the molybdenum salt is usually mixed with other fertilizers, particularly superphosphate. Sometimes molybdenum application becomes effective after liming.

The amount of molybdenum required for spray application is usually smaller, but the levels required for different crops have not been critically determined. Among the levels that have been used are 57 g of sodium molybdate per hectare or 7 g of ammonium molybdate in 14 litres of water for spraying on peas, 250 g of sodium molybdate per hectare on beet and rye, and 0.07–0.84 kg|ha on cauliflower.

A single dressing of 0.14 kg|ha has been found to remain effective for several years. In some soils and for some crops, such as cauliflowers and cabbage, heavier dressing may be required more frequently.

Liming increases the availability of molybdenum but it is usually effective in acid soils and molybdenum application usually proved easier and cheaper. Sufficient aeration, loose and friable soil, good rotation, fallowing and keeping the pH between 5.5 and 7.5 may overcome deficiency of molybdenum.

Response to molybdenum under Indian conditions: In 1964, Reddy analysed several soils of Gujarat State for total and available molybdenum and observed that it varied from 0.5 to 4.1 and from 0.12 to 0.20 ppm respectively. He noted an inverse relationship between copper and molybdenum accumulation in different crop plants. In Uttar Pradesh, Singh and Singh in 1966, analysing the alkaline soils and the soils adjacent to those, observed a negative relationship between available molybdenum and pH as well as total phosphorus in alkaline soils but not in those adjacent to them, whereas the total molybdenum and sesquioxide showed a negative correlation in both the soils. Joshi in 1956a and Pandya *et al.* in 1955 found no beneficial effect of molybdenum on *bajra* (*Pennisetum typhoides*). In 1955, Datta and Gurubasava Raj found, at the Indian Agricultural Research Institute, New Delhi, that application of 1.12 kg of molybdic acid increased the yield of berseem from 821 q|ha (in control) to 932 q|ha. According to them the succeeding crop of maize in the molybdenum-treated plots also benefited. Further work at the IARI indicated that application of 1.12 kg molybdenum per ha (to soil) along with 89.6 kg P_2O_5 per ha increased the yield of green fodder by 37.3 q|ha (over 7,389|ha control) and seed by 56 kg|ha, 180 kg|ha (of control). Soil application was more effective than foliar spray. Tamboli and Dube in 1954 and Mehrotra and Gangwar in 1964 observed significant increase in yield of berseem, whereas such effect was not noted by Kanwar in 1962a and Vithal Rao and Venkatraju in 1964. Kanwar in 1964 and Kanwar and Joshi in 1964 obtained a significant effect on the yield of rice by soil application of molybdenum to Palampur soils of Himachal Pradesh. Kanwar *et al.* in 1958–62 and Bhumbla *et al.* in 1963–65 observed significant increases in the yield of wheat in 2 out of 14 experiments on calcareous soils and in 4 out of 6 experiments on acid soils, by foliar application of molybdenum. Kanwar in 1962b observed an increase of 18.5 q|ha of potatoes over NPK alone by soil application of molybdenum. In 1966, Singh and Jain observed that molybdenum application affected the branches significantly, but it was more beneficial to the roots than to the shoots of Russian Giant cowpea. Singh *et al.* in 1969 reported that foliar application increased the cane yields. Radha in 1965 observed reduction in leaf-rot infection and increased yield of coconut by spraying molybdenum (54 ppm) for four times. Ved Prakash and Bhardwaj in 1965 reported that spraying (20 ppm) of molybdenum solution four weeks after transplanting increased the yield of cabbage. Kamalakantan *et al.* in 1966 noted slight increase in yield of cotton by foliar application of 1.12 kg|ha of ammonium molybdate.

In 1953, Singh attributed the chlorosis in citrus plants in Madhya Pradesh to lime-induced iron deficiency and obtained encouraging results by spraying ferrous sulphate. In 1954, 1960, De and Singh observed that chlorosis of sugarcane in the sandy soil was owing to iron deficiency and obtained a significant increase in growth by foliar application of 0.5 per cent ferrous sulphate. Tomar *et al.* in 1965 obtained complete recovery from chlorosis of sugarcane by spraying 3 per cent ferrous sulphate. Kanwar and Sehgal in 1964 found that leaves of rice, affected by the 'Bhurar' disease, had a lower amount of iron and a higher amount of manganese. Kanwar *et al.* in 1958–62 and Bhumbla *et al.* in 1963–65 obtained a significant increase in yield of rice by foliar application of ferrous sulphate in calcareous soils and not with neutral or non-calcareous soils. In 1964, Singh and Jain observed that sprays with iron (2.23 kg|ha) increased the rice yields by 14.6 per cent in Rajasthan. Kanwar in 1964, and Kanwar and Joshi in 1964 obtained a significant increase in yield of paddy by soil application of iron in the Kulu district. Kanwar *et al.* in 1958–62 and Bhumbla *et al.* in 1963–65 obtained a significant increase in yield of wheat by foliar application of iron in the case of calcareous, non-calcareous, neutral and acid soils. In 1959, Datta and Bains obtained increased yield of green fodder of *Jowar* by spraying iron. In 1965, Radha reported that spraying of iron (1,000 ppm) for four times reduced leaf-rot infection of coconut palms. Dargan and Sahni in 1965 reported that in their trials with different dose of iron, none of the treatments increased the yield of American cotton significantly, whereas Kamalakantan *et al.* in 1966 observed, in Tamil Nadu, a slight increase in yield of cotton by spraying ferrous sulphate at 5.6 kg|ha on the 60th day after sowing.

CHAPTER VII

APPLICATION OF FERTILIZERS

THE deficiency of nutrients in the soil indicates the type of fertilizer or fertilizer mixtures to be dressed to the soil. But their efficient utilization by the crop depends upon the method of application and the time of application of fertilizers. Most of the soils give high responses to various fertilizers as their fertility level is low, though still higher responses can be obtained when these are applied at the right time and in the right manner.

PRINCIPLES OF EFFICIENT UTILIZATION

Application based on indicated deficiency in the soil. The optimum requirement of a fertilizer for maximum production depends upon the requirements of the crop on the one hand and the deficiency of various nutrients in the soil on the other. The need for nitrogen, phosphorus and potash varies for the major crops of India. Nitrogen requirements of wheat are quite high, those of barley and *jowar* are moderate, and those of paddy and *bajra* low. The same applies to phosphorus. But the total requirements of potash for all the crops are quite high. Sugarcane has the highest requirements for all the nutrients. The optimum doses required for various crops depend upon the deficiency in the soil. This is indicated in two ways, namely, fertilizer response and soil tests.

Reducing fixation of nutrient ions. In order to be efficiently utilized by the crops the nutrients must be placed where they can be dissolved readily by the soil water. The rate and the distance to which the plant food elements can move within the soil depends upon the chemical nature of the material that furnishes nutrients and the character of the soil. Generally, phosphate ions move only a short distance from the point of placement. So, for ready availability, they must be placed where they will be utilized by the plant by root extension. Fixation refers to any chmeical or physical interaction between soluble plant nutrients and the soil whereby the nutrients become less available to crops. Soils with high iron content tend to chemically fix phosphates more readily than those with less iron content. Soils of acidic and alkaline reaction fix phosphates more readily than nearly neutral soils. To avoid progressive fixation of phosphate in soil which diminishes the efficiency of phosphatic fertilizers for a considerable period following their application to the soil, it is most essential that phosphatic and potassic fertilizers should be drilled or placed near the seed or seedling roots. This helps the cultivators in the following three ways:

1. Restricted contact of fertilizer with the soil lessens fixation of phosphorus and potash.
2. The plant food is placed within easy reach of the roots. Thus, the possibility of injurious concentration is minimised if placement is accurately controlled. On the contrary the concentration of nutrient from the fertilizers is not diluted by mixing with a great volume of soil.
3. Fertilizer placed in bands along the rows does not furnish nutrients to weeds growing between the rows.

To reduce fixation of phosphorus and potash ions to the minimum, the fertilizers supplying these nutrients must be placed in the soil. The placement may be carried out in different ways. For example, the fertilizer may be mixed with seed; it may be placed below the seedline by drilling the fertilizer or it may be placed in side bands.

In case of paddy cultivation to derive the maximum benefit from fertilizer it is very essential that the fertilizers, especially those supplying nitrogen, should be placed in reduction zone or deep in the subsoil layer to avoid loss of nitrogen by leaching. Secondly, as paddy plants take up nitrogen in the ammoniacal form during the early growth period, nitrogenous fertilizers should not be neutralized readily and should remain adsorbed on clay particles.

Time of application. Among the major plant nutrients, nitrogen is required by the field crops throughout the growth perod, while phosphate and potash are required mainly during the early growth period. In case of phosphorus it has been estimated that at a time when 50 per cent of the total phosphrous has been absorbed, only 20 per cent of the total growth occurs. As such phosphatic and potassic fertilizers are applied at the time of sowing or planting, while the time of application of nitrogenous fertilizer has to be adjusted in relation to the duration of the crop variety, and the deficiency in the soil.

Enhancing availability by correcting pH value of the soil. Soil reaction exerts tremendous influence on the availability of plant nutrients either already present in the soil or added as commercial fertilizer. The favourable reaction range for maintaining an adequate supply of nitrogen is pH 6–8. The pH range of 6.5–7.5 is most favourable for phosphorus availability. Below

pH 5.5, the phosphate may be tied up as insoluble iron and aluminium compounds and above pH 7.5 as insoluble calcium compounds. The most favourable pH range for most of the plant nutrients is about pH 6.8 with the exception of certain micro-nutrients. The availability of iron, manganese, boron, copper and zinc is greatly reduced when the pH rises above 7.5.

Under Indian conditions there is a great variation in soil reaction observed in different States. For instance, soils developed under high rainfall conditions are usually acidic, while the soils of arid and semi-arid regions are either neutral or alkaline.

In acid soils use of lime should be adopted as one of the major soil management practices. The stimulating effect of lime is primarily the effect of liberating nitrogen from organic matter by increasing the activity of soil micro-organisms. The increased availability of nitrogen and other plant nutrients causes an immediate improvement in crop yields with the use of lime. In this connection, an old saying may be quoted: "Lime and lime without manure will make both farm and farmer poor". In alkaline soil addition of gypsum decreases alkalinity and makes the nutrients available for crop growth. The addition of green manures and bulky organic manures opens up the soil and reduces alkalinity. Permanent reclamation is possible by washing out the sodium salts by leaching.

Adequate soil moisture. Nutrients are mainly absorbed by plant roots through soil solution. As such it is essential that the plant root-zone should have sufficient soil moisture for bringing fertilizers into solution. Secondly, with the uptake of nutrients plants grow faster. To balance the loss of water through transpiration, soil should have sufficient moisture. This is the main reason why fertilizers show better response under irrigated conditions as compared to response in the rainfed tract.

The water-soluble fractions of plant food elements are subject to loss by leaching in rain-water or irrigation water. Sandy soils are more subject to leaching than heavier ones, and bare soil more than those covered by plants. On an average one might estimate that loss of nitrogen by leaching is less than one-tenth of that caused by crop harvest; loss of potassium is appreciably less than that of nitrogen and loss of phosphorus is negligible. Special care is necessary in applying nitrogenous fertilizers to save losses due to leaching. On clayey and clay loam soil the total amount of nitrogenous fertilizers to be applied to the crop could be given at one time, but in case of sandy and sandy loam soils or light soils the total quantity may be given in two or three instalments depending on the duration of crop and weather conditions.

Reducing loss of nutrients by erosion of soil. Erosion or the physical removal of soil by water wind is another agency which causes loss of nutrients. This can be large or small, important or negligible, according to the degree of erosion. Correct soil conversion measures, such as bunding, terracing, cultivation on the slope, growing of legumes and grasses in strips and other measures should be adopted along with the application of fertilizers. This will greatly save loss of nutrients through soil erosion.

Application based on exchange capacity of soil. The soils contain clay minerals, organic matter and iron-rich particles all of which take part in base exchange interact with the exchangeable cations held by the soil. The nutrient ions in the fertilizers can be held by the soil particles for future use of crops up to the extent the soil is rich in organic matter and has high per cent of clay and iron-rich material. In sandy soil when large quantities of fertilizers are applied, some of the anions and cations cannot be held within the root zone and these are held by lower layers of the soil which may not be exploited by the root system. Addition of organic matter increases the exchange capacity of the sandy soils and thereby there is efficient use of fertilizers which are added to the soil. Similarly, in acid soil addition of organic matter increases its nutrient-holding capacity, and the plant roots can draw upon the nutrient supply within top surface layer of the soil.

METHODS OF APPLICATION

The three methods of distribution of fertilizers are: broadcasting, localized placement and spraying of plants with solutions of fertilizers. The situations under which these methods prove successful are different. Broadcasting proves effective when the crops have a dense stand, when the plant roots permeate the whole volume of the soil, on rich soils, when large doses are applied, when the nitrogenous fertilizers are readily soluble, and potash fertilizers on light soils and insoluble phosphatic fertilizers such as basic slag are used. The localized distribution is used for small quantities of fertilizers, for application of phosphatic and potash fertilizers of high fixation capacity, when plants are spaced widely apart, root-system development is poor, and soils have low level of fertility. The fertilizers are sprayed when nutrients are absorbed

with difficulty by way of the soil and the roots, and when nutrients are required in smallest possible quantities.

There is a distinction between *placement* and *localized placement*. The former refers to applying fertilizer into the soil, but without special reference to the location of seed or plant and the latter implies the application of fertilizer into the soil close to the seed or plant.

Broadcasting. Evenly spreading the dry fertilizer over the entire field and either incorporating by cultivation or after the seed has been sown is generally termed broadcasting. In the former case the fertilizer may be ploughed in with a furrow-turning plough or with a cultivator. When it is ploughed in the fertilizer is automatically placed in plough sole layer. The material applied after the crop has been seeded in rows is termed as 'side-dressing'. The broadcasting of the fertilizer to broadcast sown crops or seeded in narrow rows is called 'top-dressing'.

In India most of the fertilizers are broadcast manually. The material is carried in baskets and applied as 'side-dressing' or 'top-dressing' as the case may be. In other countries fertilizer spreaders are in use. The low-down gravity-type spreaders are more in common use than the centrifugal type of spreaders. Where extensive areas are to be fertilized, the materials are broadcast by aircraft particularly in hilly regions or for paddy fields where machinery cannot operate. The most popular aircraft for broadcasting is the Tiger Moth which can carry 300 kg of fertilizer. In recent years larger aircrafts to carry 700 kg of fertilizer have been developed and are operated in the U.S.A. and New Zealand. The farmer is capable of spreading 10–60 metric tons per day depending upon the distance of the air-strip to the fields and weather factors. Granulated superphosphate gave the best distribution pattern with satisfactory overlap, with aircraft flying at 120 metres altitude in lanes 2.7 metres apart; low-flying, 15-metre elevation is adopted with cross-wind technique when the materials are not granulated for even distribution of fertilizer.

Besides the advantage of top-dressing in inaccessible areas, aircraft top-dressing ensures even distribution of very small quantities of fertilizer (such as micro-nutrients) over large areas. It is useful for application of high analysis material, where the bulk is small and when combined application of fertilizers and insecticides is desired, and the cost of labour for manual distribution is high.

In pastures and natural grasslands it is usual to top-dress nitrogenous, phosphatic and potassic fertilizers. In crops nitrogenous fertilizers are the ones which are generally broadcast after germination of the crop. This may be applied in one dose or two and more split-up doses.

Disadvantages of broadcast application: 1. The weed growth is stimulated all over the field and the full benefit of the fertilizer is not derived.

2. The fertilizer worked into the soil before sowing or applied after sowing cannot be fully utilized by plant roots as few nutrients move laterally over long distances and the roots cannot exploit every particle of the soil.

3. The fertilizer when dissolved in water forms a weak soil solution, as it is spread over a wide field and cannot be fully absorbed by the plant.

4. By broadcast application the fertilizer nutrients come in contact with a large mass of soil and they are fixed to a greater extent than by proper placement.

Localized placement. Recent investigations on the release of nutrients and their uptake, conducted in the U.S.A., have shown that a few roots can completely lap up the localized-placed fertilizer band. The uptake of phosphate from a fertilizer is largely independent of the overall phosphate status of the soil. The uptake of phosphate is much greater when nitrogen is present in the band. The immobile nutrients in a fertilizer band affect only an inch in diameter on heavy-textured soils but on light soils they may move out about two inches in diameter. The complex system of band placement is governed by the factors of biology of micro-organisms, soil reaction, temperature, moisture status, aeration, etc. For instance, when chloride is present in the band, soluble salts are formed which significantly increase the oleotic concentration and also influence the pH value. These in turn influence the movement of water into the band, microbial activity, root physiology and chemical reactions in the band. Similarly nitrogen and potassium fertilizers also increase the salt content of the soil solution more than phosphate fertilizers. When heavy dressings of NPK mixtures are required the benefit of placing phosphorus near the seed or plant may be offset by the injury caused by very high concentration of soluble salts containing nitrogen and potassium.

Further investigations have shown that high microbial activity may sometimes be responsible for poor germination and the decay of seeds. However, modern machinery can be adjusted to properly place the fertilizer at convenient distance from the seed.

The recognized methods of placement are: (*i*) drill placement, (*ii*) plough-sole placement, (*iii*) band placement, (*iv*) spot placement, and (*v*) injection of liquid fertilizers. Each is suitable for a particular fertilizer, for different crops and for particular situations.

Drill placement: This is the commonest method for preplanting application of fertilizers for cereals and row crops. Sometimes the fertilizer is mixed with the seed and is dropped into the furrow at the same spot. This is suitable only for cereals when small quantities of materials are applied. There are seed-*cum*-fertilizer drills which have separate seed box and fertilizer hopper with drills attached so that the fertilizer and seed are drilled in separate furrows, and almost in level with each other. This is a better method where large quantities of fertilizers can be safely applied without likely injury to seed from the contact of concentrated fertilizer or similar injury to primary tender roots of seedlings. Both animal and tractor-drawn, seed-*cum*-fertilizer drills are in use. The former are less common than the latter.

Drill placement can be practised with *desi* (country) plough also. Here the *nari* or drill is tied to the implement and depth is adjusted to ensure placement at the moist layer. When the doses are low, less than 9 kg N or P_2O_5, the fertilizer mixed with seed can be placed through the same drill. Larger doses are applied through a separate drill which is adjusted to place the fertilizer 5–6.25 cm below the seed layer. For monsoon season crops or where the top-soil layer has enough moisture, the fertilizer may be drilled and seed drilled manually in the furrow. As labour cost in Indian agriculture is a factor of inconsequence this method of drilling is being rapidly adopted in various parts of India. In the case of transplant-paddy the drill has a shoe to protect it from clogging with wet soil mass. After puddling the excess of water is drained off. The fertilizer is placed through the drill tied to the plough with shoes on it. This places the fertilizer to a depth of 15-18 cm below the ground. Thereafter the paddy is transplanted on the same rows, where fertilizer had been drilled.

The results of drilling fertilizer at various depths for the maize crop are given below:

TABLE 34. MEAN YIELD OF MAIZE IN RELATION TO DEPTH OF DRILLING (YIELD IN KG/HA)

Treatment	Method of application		
	Broadcast	Depth of drilling below seedline	
		6.25 cm	11.25 cm
135 kg P_2O_5/ha ..	1,644	1,808	1,790
67.5 kg P_2O_5/ha ..	1,616	1,771	1,699
45 kg P_2O_5/ha ..	1,450	1,597	1,570
Mean	1,570	1,725	1,662
Per cent increase over control	..	918	532

The results of nitrogen placement are summarized in Table 35.

Similar results were obtained with paddy in the experiments conducted for two seasons.

The drilling of nitrogen significantly increased the yield of grain in paddy. The difference in favour of drilling was 660 and 761 kg|ha in 1957–58 and 1958–59, respectively, which ranged from 11-12 per cent. The tillering, growth in height and grain weight per hill were all increased. There was slightly more lodging in the heavier crop although the grain to straw was narrower in the drilled than in broadcast treatments respectively. The experiments conducted in Japan on application of urea have definitely established that deep placement in gravelly or sandy soils which have free drainage exceeding 20 cm per day reduces the yield than surface application just before transplanting. In soils, where drainage is slow and leaching of nitrogen is not a serious problem, the deep placement has given better results than surface application. In such fields paddy soil differentiates into upper oxidative and lower reductive layers. In the former, nitrate is the stable form of nitrogen and in the latter ammonia. In the oxidative layer ammonia is oxidised to nitrate which, coming down to the reduction layer, is subject to various changes and thus is liable to be lost. On this basis it is desirable to place urea in the reductive layer. The urea gives best results when placed deep in the soil.

TABLE 35. MEAN YIELD OF MAIZE IN RELATION TO DEPTH OF DRILLING (YIELD IN KG/HA)

Treatment	Method of application		
	Broadcast	Depth of drilling below seedline	
		6.25 cm	11.25 cm
22.5 kg N/ha	1,487	1,570	1,478
45 kg N/ha	1,515	1,570	1,588
67.5 kg N/ha	1,625	1,634	1,918
Mean	1,542	1,588	1,662
Per cent increase over control	..	275	706

Plough-sole placement: The fertilizer is placed in a continuous band at the bottom of the furrow in the process of ploughing with a furrow-turning plough. Every band is covered by the succeeding inverted earth. Here the fertilizer is broadcast on the field prior to ploughing. This is commonly practised in the U.S.A., particularly in soils having a heavy clay a little below the plough-sole. Thus, the fertilizer is placed in moist soil where roots are concentrated and it remains more available to plant roots during the dry season. In recent years fertilizer applicators have been evolved and are in use for heavy dressing. These place the fertilizer 40–55 cm apart in bands at, or slightly above, the plough.

Band placement: This is a system of localized placement of fertilizer by the side of the plant, in the hill or along the row of crops. This is in a definite space relationship to the seed or plant. In the drill placement the fertilizer is placed in the same furrow as the seed, whereas in band placement the fertilizer is placed in a continuous or discontinuous band to the side of the seedling some distance away from it and either at level with the seed, above the seed level or below the seed level. The fertilizer is generally placed near the seed by the machine or by means of an attachment on the planter. Band placement is usually practised at the time of seeding. When proper machinery is available it can save labour and make more efficient use of small amounts of phosphorus, potassium or mixed fertilizer. The fertilizer may be placed in a single or double band. In an experiment conducted on potato at the Indian Agricultural Research Institute, New Delhi, the increase in yield was 8 per cent under single-band placement and 14 per cent under double-band placement.

Normally, the band distance from the seedline varied from 2.5 cm to 7.5 cm and it is at the same level as the seed. Where the moisture is inadequate in the surface layer and size of seed is small, the band is placed two to four inches below the seedline so that the fertilizer is placed in the moist layer. Deeper placement is advocated for light sandy and gravelly soils and shallow placement for heavy soils.

The experiments on corn conducted on Wankegan silt loam (Minnesota) in the years 1954 and 1955 on the whole gave extra response of 12.5 bushels when 25:50:50 fertilizer was dressed 5 cm below seed level and 6.25 cm laterally over broadcast application of fertilizer.

An experiment on band placement of nitrogen was conducted at the Indian Agricultural Research Institute during 1958–59 and 1959–60.

In both the years band placement of nitrogen gave higher yield of cotton than broadcast application. The difference between the two methods of placement was small in 1958–59, but it was significantly higher for placement of fertilizer in bands 10 cm deep in the middle of inter-row space, i.e., 37.5 cm from the seedline either way. These differences were observed in all the pickings in both the years.

Spot placement: Sometimes the fertilizer is placed in between the plants in pinches at the base of each pair of plants. In Java the nitrogenous fertilizers are applied by scoop into holes drilled by means of a peg. The bamboo peg has a hole at the bottom and through this bamboo the fertilizer is dropped with the scoop. In the U.A.R. and Sudan a similar method of applying is practised for cotton crop and in China for sugarcane, tobacco and cotton. This is a very suitable method of application in vegetable crops.

The localized placement of fertilizer has following advantages over broadcast application: (i) There is the minimum content of soil with the fertilizer and the fixation of nutrients is appreciably reduced. (ii) The fertilizer is within easy reach of the seedling and as it does not come in contact with the sensitive seeds they are not injured, and no loss occurs in stand of the crop. The injury is maximum in dry sandy soil when fertilizers are concentrated, e.g., urea. (iii) The fertilizer is placed in the moist layer where roots readily penetrate and can absorb the nutrients in solution. (iv) The weeds all over the field cannot make use of the fertilizer. Ammoniacal ions are converted into nitrate ions in the soil by bacterial activity. (v) Recent researches on corn have shown that a single root is sufficient to supply all the nutrient requirements of the plant, if the supply of nutrients is adequate and the absorbing system takes in the supply. Such a root may remain active for the entire season and continue to absorb the nutrients. The band placement, thus, does not require a very extensive root system to draw up the nutrients. (vi) In the fertilizer band the high ion concentration facilitates their movement into the roots. This is due more to intensity than capacity factor of the root surface as very few roots tap the bands of fertilizers. (vii) The residual response of the placed fertilizer is greater than that of broadcast application.

In the maize experiment, Table 35, the extra response with 6.25 cm placement was 21.2 kg and with 11.25 cm drill placement 28.7 kg respectively, over broadcast application. Similar results have been obtained in the cotton experiment. Thus, the loss of nutrients is reduced.

Injection of liquid fertilizer: Anhydrous ammonia has become very popular in the U.S.A. on most of the farms, as the unit cost of nitrogen in this is extremely low. In India it is likely to become very popular in due course. Several other liquid fertilizers which can be transported under low pressure compared to 14 kg|cm in case of anhydrous ammonia have become popular in several other countries. For their application several soil injecting machines have been developed. The heavy steel tank on the injecting machine normally has 450-900 litres capacity and is equipped with automatic safety valves. There is a meter attached with the machine. The shoes are of various designs but have low draught; they are narrow in size and are of lister-type. The shoes run at a depth of 15–25 cm and the gas is injected at the bottom of the shoe. At the Hebbal Farm, Mysore State, an animal-drawn anhydrous ammonia application has been successfully developed. It consists of a gas cylinder mounted on a wheel-cart wherefrom the gas enters into the soil furrow behind a type of cutler. Anhydrous ammonia losses are low when the soil is neither too dry nor too wet, but otherwise serious losses of nitrogen occur. The soil should have good tilth and should have enough moisture. The ammonia is immediately fixed in the base exchange on colloidal particles of the soil.

TIME OF APPLICATION

Proper timing of the application of fertilizers is another factor that conduces to their efficiency. The nutrient salts in fertilizers are of two categories, mobile and immobile. The mobile ones consist of nitrate, chloride and sulphate, and the immobile ones are phosphorus, ammonium, potassium, calcium, magnesium, strontium, cobalt, iron, molybdenum, zinc and manganese. Of the latter ammonium ions can be nitrified into nitrate ions by microbial activity under optimum conditions of soil moisture, aeration and temperature. Thus, nitrogenous fertilizers should be applied at the peak requirements, while phosphorus and potassium can be applied at planting time. Besides, it has been observed that phosphorus is required early in the life-cycle of the crop for optimum development of root system and later on for seed setting in cereals and fruit development in other crops. But for optimum uptake of phosphorus it is essential that it should be in mixture with nitrogen. However, fertilizer combination should be such that uptake is encouraged. In corn, placement in band of monoammonium phosphate and ammonium sulphate combined gave higher uptake than monoammonium phosphate. The uptake was depressed when the band consisted of monoammonium phosphate and calcium nitrate. Application of ammonium sulphate helped to keep the phosphate in a soluble form and effected a greater uptake of phosphorus. The presence of calcium reversed the phosphate into insoluble form. The uptake of phosphorus is also influenced by the kind of potassium salts consisting of phosphate, chloride, sulphate, nitrate, bicarbonate and hydroxide. The uptake of phosphorus was maximum from potassium phosphate (KH_2PO_4).

It is essential to maintain an optimum balance of nutrients for successful growth. For early optimum growth a good balance of N, P and K is desirable. In the later stage the maximum requirements are for nitrogen during the grand growth and seed-formation stages. In long-duration crops it appears necessary to top-dress the nitrogenous fertilizer at later stages of the crops. The schedule standardized for the sugarcane crop in Bombay Deccan is given in Table 36.

In all cases the crops are started with small doses. In early crop a substantial dose is applied at six weeks, while in medium season and *adsali* crop this is dressed at eight weeks. In the medium season a dose is dressed at 12 weeks but in early and late season this is applied at 16 weeks. The balance in all cases is applied at earthing up of the crop.

TABLE 36. RECOMMENDED SCHEDULE OF APPLICATION OF NITROGEN TO DIFFERENT TYPES OF SUGARCANE CROP FOR DECCAN CANALS' IRRIGATED AREAS

(Nitrogen in kg|ha)

Time of application	Type of sugarcane crop					
	Seasonal crop		Pre-seasonal crop		*Adsali* crop	
	A/S	Oilcake	A/S	Oilcake	A/S	Oilcake
At planting ..	33.7	..	42	..	50.4	..
Six weeks ..	22.5	112	..	..	..	..
Eight weeks ..	..	..	28	140	33.7	168
Two weeks ..	..	..	42	..	..	..
Six weeks ..	33.7	..	..	..	50.4	..
Earthing up ..	22.5	112	26	140	33.7	168
Total ..	112	224	140	280	168	336
Grand total ..	336		420		504	

The results obtained at 11 centres where the effect of time of application of nitrogen was studied under the 'Fertilizer Use Project' during 1953–56 is given in Table 37.

In early varieties application of 13 kg in two split doses, half before transplanting and half at tillering, gave the best response. In midseason varieties, half-dose application at planting and half at tillering showed the maximum response. In late-season (long-duration) varieties the best response was obtained by applying one-third at planting, one-third at tillering and one-third before flowering.

The results of experiments conducted on time of application of nitrogen on cotton during 1958–59 and 1969–60 are given in Table 38.

TABLE 37. RESPONSE TO TIME OF APPLICATION OF 13.6 KG N TO VARIOUS DURATION PADDY VARIETIES

Time of application	Duration of paddy variety		
	Early	Mid-season	Late
Before planting	5.7	5.3	5.3
At planting	5.5	4.8	6.6
At tillering	5.8	4.8	6.7
Half before planting + half at tillering	6.8	4.4	6.8
Half at planting + half at tillering	6.2	5.5	6.3
One-third before planting + one-third a week before flowering ..	6.5	5.3	9.8
One-third at planting + one-third at tillering + one-third at a week before flowering ..	5.2	4.7	11.1

During the first year when yields were low for the second and third pickings the application of half dose of nitrogen at planting and half at flowering gave significantly higher yield than full dose at planting or at flowering. In the next year the full dose application at planting gave significantly higher yield than T_2 and T_3 treatment. Thus, late application of nitrogen is not beneficial for cotton crop.

TABLE 38. RESPONSE TO TIME OF APPLICATION OF NITROGEN ON COTTON (kg|ha)

Yield of cotton at different pickings	1958–59			1959–60		
	T_1	T_2	T_3	T_1	T_2	T_3
1st picking	473	494	451	621	567	515
2nd picking	254	316	266	525	526	452
3rd picking	91	207	95	366	332	293
Total	899	1,130	889	1,568	1,511	1,260
CD at 5%		27			39	

T_1 = Full dose at planting; T_2 = Half dose at planting and half dose at flowering; T_3 = Full dose at flowering.

SPRAYING OF FERTILIZER SOLUTIONS

In recent years considerable progress has been achieved in spraying of fertilizer materials on crops. Several nutrient elements are readily absorbed by leaves. The precautions necessary are: (*i*) strong solutions should not be applied; (*ii*) the rate of application should be low to facilitate absorption of nutrients; and (*iii*) where high or moderate fertilizer rates are envisaged several applications may be necessary. Micro-nutrients are required in small quantities and their solutions are not strong. Their application by foliar spray has given better results compared to soil application. In solution for foliar spraying their normal dose can be substantially reduced as this avoids chemical fixation of micro-nutrients in the soil. The doses of micro-nutrients suitable for application per ha are: $ZnSO_4$ 0.22–4.5 kg; $CuSO_4$ 0.45–2.26 kg; $MnSO_4$ 0.022–0.9 kg; $MgSO_4$ 2.26–4.53 kg; $FeSO_4$ 2.26 kg; Borax 0.45–2.26 kg; Molybdic oxide 0.45–1.36 kg. The actual dose depends upon the degree of deficiency in soil and pre-disposing factors to it. In wet years sandy soils of desert areas showed varying degrees of response but in dry years the response to Fe was very high. Thus, a mixture of these nutrients is to be sprayed under such conditions.

Since urea is an organic form of nitrogen, it causes the least injury. It can be sprayed at the rate of 2–4 per cent depending upon the structure of the leaf. Three kilograms of urea in 500 litres of water has been reported safe for wheat, apples, tomatoes and maize, but a solution twice as strong usually causes some marginal leaf burns. Sugarcane can tolerate 4 per cent solution of urea. Pritled urea should be avoided for application as it contains biuret (formed in the process of prilling) which is toxic to plants. By foliar spraying of urea the top-dressing dose can be almost halved. Similar effect of the foliar spray of the phosphate solution was observed on tomatoes. Such application brought about early flowering and early fruit set.

CHAPTER VIII

SOIL FERTILITY ASSESSMENT BY SOIL-TESTING SYSTEM

In the early days of agriculture producing plentiful crops in India was primarily a matter of preparing the seedbed, cultivating and harvesting. Today the situation is different. The high fertility of our soil has gone down and the average yields of our good crops are the lowest in the world. To maintain successfully high crop production in the face declining soil fertility, farmers should know the basic facts of plant-food requirement and the capacity of the soils to produce it and also what goes on in soils.

SOIL FERTILITY

To understand clearly some of the problems involved in producing crops in area where soil treatment is necessary, one needs to know what the terms soil productivity and soil fertility imply. Soil productivity is a rather broad term used to indicate the crop-producing ability of a soil. Soil fertility refers to the plant-food supply in the soil. Fertile soils are well supplied with available plant food either naturally or as a result of good soil treatment programmes. Producing satisfactory crops is not solely a matter of ample soil fertility. In the production of crops several factors are involved, and yield can be expressed as a function of climate, crop, soil and management.

Chemical tests for soil fertility. A large number of our soil scientists and agronomists in the past were adopting the so-called 'Bank Concept', a concept of soil management which broadly meant that every plant nutrient that had been removed by the crop could be replenished by adding that much quantity of nutrients in the form of fertilizer to maintain high soil fertility. This concept, however, worked only under limited conditions.

The problem of determining the fertilizer needs of a soil by means of chemical method has received considerable attention in recent years. This has been due to the introduction of new methods designed for this purpose.

The first chemical studies concerned themselves with the total analysis of the soil, but no practical correlations between the total amount of an element and the need of the soil for that element were secured. Towards the end of the last century the concept of measuring the availability of the fertility elements in the soil became fully developed. The citric acid solubility method of Dyer is the most striking example of this school of thought. The results secured were much more promising. Broad correlations between the amounts of the elements extracted by such methods and the crop response to added elements were secured. These studies, however, failed to lead to specific correlations and no recommendation for the general use of any of these methods as a practical indicator of soil fertility could be made.

The concept upon which the new school bases its method of study can be stated in a few sentences. Usually more than one form of an element occurs in the soil at any one time. Each form contributes to a greater or lesser extent to feeding by plant's roots. The significance of each form to the growth of each crop under varying conditions can be established by studies of plant growth and soil chemistry. The form or forms found to be of most significance to the immediate growth of the plant can be measured chemically and this information can serve as a partial basis for recommendations.

The form or forms to be tested for must be determined by chemical and fertility studies using the types of crops and soils on which the tests are to be applied.

A practical test or method is one which has been calibrated against actual crop response under the conditions concerned. A test practical for one condition will not necessarily be practical for another condition until the necessary correlations have been established.

To be of practical value to a farmer the results of a test must be applicable under the soil management and cropping system used.

The study of soil fertility from the standpoint of fertilizer needs has followed mainly three general methods: experiment field methods, pot-culture methods, and chemical study of the soil and the plants growing in the soil. Each of these methods is more or less dependent on the results of the other methods for the interpretation of the results secured.

SOIL TESTING

Soil tests might be defined as laboratory procedures which measure some fraction of the total supply of nutrients in the soil. To be valid these tests must be carefully calibrated with response of different crops to the application of fertilizers. Recommendations

made to a farmer are based on the relationship between the soil test and the outcome of closely controlled fertility experiments. Soil testing reveals a rather complex set of relationships and procedures, involving precise chemical analytical methods and a vast amount of agronomic research.

The knowledge gained through this research in one soil area will not apply to all soil areas because of basic differences in soils. However, adequate research in each soil area and soil classification will bring out the productivity status of individual soil groups, upon which recommendations of fertilizer dose could be given through soil tests.

Once it is established that a specific nutrient is affecting the performance of a crop, fertility trials are conducted over a general area, usually state-wise, to determine the extent of occurrence in other soils. Calibration of the test for a specific measurement, then, is the key to making the soil test work.

To bring about increased crop production in the country through the optimum fertilizer use, the Government of India under an Indo-U.S. agreement decided to establish 24 Soil-Testing Laboratories throughout the country with the specific objective of analysing the soils from the farmers' fields and giving fertilizer recommendations.

The soil samples sent by different agencies are analysed in laboratories and recommendations made on the fertilizer needs. This analysis is done free of cost at present. The details of the procedure are given below.

Collection of soil samples. If the soil sample is not properly collected, the soil test may be worthless. Soils vary from ha to ha and even from metre to metre in any field. It is most important to collect a representative sample which will represent the average condition of the field or area. No amount of improvement in the laboratory techniques can compensate for a poorly collected sample.

Procedure for collecting soil samples

1. Sample each field separately. When the areas within a field distinctly differ in crop growth, in the appearance of soils, in elevation, or have been cropped and manured differently, divide the field and sample areas separately.

2. Take a composite sample for each area. Scrap away surface litter, then take a small sample from the surface to plough-depth in 15-20 spots. Collect these samples in clean gumla or cloth bag.

3. Where crops have been planted in lines, sample between the lines.

4. Do not sample unusual areas. Avoid areas which have been recently fertilized, old bunds, marshy spots, and areas near trees or compost.

5. Use proper sampling tools. Satisfactory samples can be taken with a soil tube, an auger, a *kassi* or a *khurpi*.

6. Take a uniformly thick sample from the surface to plough-depth. If a *kassi* or a *khurpi* is used, first dig a V-shaped hole.

7. Scrape a corner of the blade from bottom to top of the exposed soil-face, collecting the sample on the blade or in your hand. Mix samples well by stirring with hands on a clean piece of cloth or paper.

8. Discard all but one pint by quartering. Quartering ensures a representative final sample. The sample should be dried in the shade for an hour or two before putting into container (cloth bag).

9. Each cloth bag or carton should be capable of holding a pound or two of the soil.

10. Label the container properly giving the soil the serial number, date of collection and name of the person who collected it. Fill the information sheet and send it along with each sample.

11. If the soil is too wet do not sample until the moisture status is such that you can handle the soil conveniently.

12. If the soils are too wet they may be air-dried, but do not heat the soil.

13. The soils may be sent to the nearest soil-testing laboratory for analysis.

A sample of the information sheet, which may be filled in while sending the samples, is given in Proforma A.

At least one sample should be collected from each field once in every three years for getting fertilizer recommendations.

Agencies for collection of soil samples. In India, because of the large number of illiterate farmers, it should be expected that most of the farmers will not be in a position to collect the soils. The extension workers and the village-level workers of the Community Project areas, National Extension Blocks, and field staff of the State Agricultural Departments have to help the farmers in the collection of soil samples. The Block Development Officers have to take up this work as a part of their agricultural improvement programme, supply the cloth bags free of cost, and offer technical assistance. The fertilizer dealers can be of great assistance, but in view of the inadequacy of the fertilizer and limited sales by private agencies, there is a limited scope of covering a number of farms. The soil-testing staff also have instructions to collect the soil samples from the farmers' fields when they visit any particular area. The soil-testing chemists supply the details of the method of collecting the soil samples as well as the information sheets which accompany the soils. The village-level worker and the Agricultural Extension staff of the Community Project areas are trained periodically in the proper collection of soils by the soil-testing staff.

Transport of soil samples. The best arrangement will be to pack the soil samples nicely and despatch them by post or by railway parcel in case the place is on the railway line.

Analysis of the soils in the laboratory. When the soils are received in the laboratory, they are registered, air-dried and powdered for proceeding with the chemical analysis. The set-up of the soil-testing laboratory is such that about 50 soil samples can be handled in a day. This is possible because of the volume measurements of soil with scoops, and the use of racks for handling in sets of ten samples at a time, both for extraction, filtration and introduction of colorimetric and flame photometer methods for the estimation of nutrient elements. The efficiency of the daily output of the samples can be further improved by the introduction of automatic pipettes and automatic dispensers.

At present the soils are being analysed for available phosphate, potash, nitrogen, organic carbon, pH and soluble salts. With these estimations it is reasonably possible to judge the fertility status of the soil and assess the fertilizer requirements.

Methods used in the soil-testing laboratory. The following methods have been recommended for use in the soil-testing laboratories for the estimation of the six constituents, namely, available phosphate, available potash, available nitrogen, organic carbon, pH and soluble salts:

1. Available phosphate: (a) Olsen's method for soils with pH above 6.
(b) Bray's method for soils with pH below 6.

Limits :
Low: Less than 22.4 kg P_2O_5 per hectare: Medium: 22.4–56 kg|ha;
High: Above 56 kg|ha.

2. Available potassium: (a) Exchangeable potash with neutral ammonium acetate.
   (b) Potash extracted with Morgan's extractant.

Limits :
Low: Less than 112 kg|ha; Medium: 112-280 kg|ha;
High: 280 kg|ha.

3. Available nitrogen: (a) Alkaline permanganate method.

Limits:
Low: Less than 280 kg N per hectare. Medium: 280 kg–560 kg N per hectare;
High: Above 560 kg N per hectare.

4. Organic carbon: Walkely Black's rapid titration method.
5. Soluble salts: Solubilized in 1:2 soil-water extract.
6. pH: 1:2 soil-water suspension.

Fertilizer recommendations on the basis of soil tests. From the soil-test results and the information supplied by the farmer on the information sheet, and on the basis of experience gained by the method of functioning of fertilizers in the soil and the nutrient requirements of different crops, recommendations are given for the application of lime in the case of acid soils. The dose of fertilizer to be applied and other soil management practices are suggested for giving increased yields. A sample of the soil-test report and recommendations form are given in Proforma B.

The soil test report is sent back to the farmer with the recommendations. A copy of this is also sent usually to the Block Development Officer so that his staff can explain the recommendations and make available the fertilizers necessary for the purpose.

SOIL–TESTING KIT

The soil-testing kit is an assembly of required chemicals and apparatus in a small box for easy transport and examination of the soil in the field itself.

A soil-test kit for use in the Indian soils has been prepared at the Indian Agricultural Research Institute, specially for the use of field assistants and the farmers. (Raychaudhuri, S. P. and Subbiah, B. V. 1958. *Soil-Testing Kit.* Indian Coun. agric. Res. 14).

This kit is useful for the ready estimation of pH, available phosphate and available potassium in soils. The reagents in this kit and the method of using it are essentially the same as those of the soil-testing laboratories. In order to ensure good results the kit should be handled only by agricultural extension workers having a B.Sc. degree in agriculture or chemistry, or those who have been specially trained for the purpose.

Soil test summaries and fertility maps made on the basis of the soil tests. A soil-test summary furnishes specific information that can be used to assess the fertilizer needs of an area. When large number of soil tests are made, it is possible to summarize the soil test for any particular area and these summaries show the general fertility levels.

When the samples are collected at regular intervals in any particular area, like a village, fertility maps showing the nutrient status can be prepared for the use of extension workers for recommending the fertilizers.

PROFORMA A

(To accompany soil samples)

Soil-Testing Laboratory
I.A.R.I., New Delhi

To be filled by Soil-Testing Lab. I.A.R.I.
....

Date of sample taken...........Collected by................
Sample No. ....
Report to be sent to ....

Field location:
Name of cultivator/owner ....
Village .... P.O./Thana .... District ....
Survey No. ....
Any other information to locate the area completely......

Sample:
Depth of sample ....
No. of subsamples to get the composite sample ....
Moisture condition when sampled.....Moist.....Dry.....
No. of hectares in field...No. of hectares represented by sample ....
Soil: Local name .... Texture ....
Group .... Revenue class ....
Tick the conditions that apply to this soil:

Lay of land:	Level	Drainage:	Good
	Rolling		Fair
	Steep		Poor or water-logged
Erosion:	None	Elevation:	Upland
	Slight		Lowland
	Severe	Crop growth:	Normal
			Poor

PROFORMA A (*Concld*)

Special soil conditions:	Impermeable subsoil:	How does the soil plough:	Easy
			Hard
	Saline condition		

Past history of field (last 2 years)

Year	Crop		Fertilizers and manures used/hectare				Green manuring if practised	
	Name	Yield kg/ha	Fertilizer		Manure			
			Name	kg.	Name	Cart-load/acre	Crop	Year
Present crop or (*rabi*) or Crop last grown (*kharif*).								
Crop one year ago (*rabi*) (*kharif*).								

Crop to be grown for which recommendation is asked for........
Rotation of crops to be followed..........................
(Starting with crop to be grown)
Crop irrigated or *Barani*/rainfed

Irrigation:	Well	Well water:	Brackish
	Canal		Good

State special problems and remarks here.................

Note—Soil-testing is a free service to the farmers of Delhi State and they can send as many soil samples as they desire to get tested (MAKE FULL USE OF THIS SERVICE)

Soil-Testing Laboratory, I.A.R.I., New Delhi.

PROFORMA B

SOIL-TESTING LABORATORY
INDIAN AGRICULTURAL RESEARCH INSTITUTE
NEW DELHI

Soil-Testing Report and Recommendations

1. Name of cultivator:
2. Name of village, P. O., etc.:
3. Date of collection:
4. Location of the field with respect to village, road, etc.:
5. Cropping history with yields for two years:
6. Manures and fertilizers:
7. Texture:
8. Your soil has the status with respect to different constitutents as shown below:

Acidic below pH 7	Normal pH 6.8	Tending to become alkali soil pH 8–8.7	Alkali soil harmful above pH 8.8

(a) Soil reaction or pH

Normal	Critical for germination	Critical for growth of salt-sensitive crops	Severe injury to plants

(b) Salinity expressed as conductivity in millimhos/cm at 25°C

Very low	Low	Medium	High	Very high

(c) Organic carbon (%)

(d) Available phosphorus in kg/hectare

PROFORMA B (*Concld*)

(e) Available potassium in kg/hectare

9. You may take the following steps to improve the soils:
10. You may apply the following fertilizers:
    1. Organic manure
    2. Superphosphate
    3. Ammonium sulphate
    4. Muriate of potash or potassium sulphate

Assistant Soil Chemist
Division of Soil Science and Agricultural Chemistry
I.A.R.I., New Delhi-12

Copy forwarded for information to:
The Block Development Officer

CHAPTER IX

SOIL INOCULANTS—BACTERIAL AND ALGAL

Inoculation of soil or seed with an active strain of micro-organism in sufficient numbers is called soil or seed inoculation. The various methods used for inoculation with bacteria and algae are described in this chapter.

BACTERIAL INOCULANTS

Inoculation with Rhizobium: The rhizobia or the legume root-nodule bacteria are the organisms that function in association with the host plant and fix atmospheric nitrogen. Estimated amounts of nitrogen fixed from the air by legume bacteria in different legumes, grown in the U.S.A., are given in Table 39.

TABLE 39

Legume	*Nitrogen fixed in kg/ha*
Alfalfa	217
Sweet clover	134
Ladnio clover	200
White clover	115
Alsike clover	134
Crimson clover	105
Lespedezes (annual)	95
Soybeans	65
Peas	81
Cowpeas	101
Winter peas	56
Vetch	90
Beans	45
Peanuts	47
Lupins	169
Velvet beans	75
Sour clover	110
Kudzu	120
Fenugreek	92
Bur clover	87
Lentils	115
Garbanzos	74
Pastures with legumes	119

fide Pelczar, Michael, J. and Reid, Roger, D. 1958. *Microbiology*. page 484, Table 363. McGraw-Hill Book Co., Inc., New York.

In India the amount of nitrogen fixed by legumes each year varies from 50 to 150 kg per ha. In experiments at the Indian Agricultural Research Institute, New Delhi, it was observed that sunnhemp and cowpea fixed 90 kg nitrogen each, berseem 120 kg nitrogen and *arhar* 140 kg nitrogen per hectare per year.

The efficiency of selected strains of legume bacteria used for seed inoculation was clearly demonstrated in some of the experiments conducted in Tamil Nadu by Rajagopal Iyengar in 1960. The fixation of nitrogen by legume is appreciable if superphosphate is applied to the fields at the time of sowing. Experiments at Coimbatore showed that the increase in the total nitrogen content of the soil was 10-20 per cent in cluster beans, red gram and sunnhemp plots. As a result of continuous growing of inoculated legumes, specifically for green-manure purposes over a number of years, it was observed that the increase in soil nitrogen over control ranged from 84-146 kg per ha and the yield of paddy from 190-207 per cent for grain and 302-417 per cent for straw.

The beneficial effects of including legumes in rotations succeeding cereal crops have been amply demonstrated through experiments in this country and abroad.

At Hebbal Farm (Mysore State), the yield of *ragi* (*Eleucine coracana*) increased by about 30 per cent when grown in rotation with groundnut. Experiments at Tindivanam (Tamil Nadu) showed that the yield of *cholam*, *cumbu*, and *varagu* increased by 124 per cent, 49 per cent and 119 per cent respectively after groundnut. Experiments in lysimeters and the field, conducted at the I.A.R.I., showed that wheat crop, following phosphate-fertilized berseem, and cowpea inoculated with specific rhizobia, recorded increased yields over wheat following *maruwa*, another cereal crop. This was reported by Desai *et al.* in 1953, Parr and Bose in 1947; and Sen and Bains in 1951. Experiments conducted by Acharya *et al.* in 1953 at the I.A.R.I., showed that berseem rotated with cowpea and wheat resulted in significant increase of nitrogen and organic carbon when berseem crop was adequately manured with phosphates. They found vigorous microbial activity and higher microbial population in plots treated with phosphates. Ammonification, nitrification and nitrogen fixation also increased in these plots.

The cultivation of inoculated legumes with the application of phosphates helps in the reclamation of saline or alkaline soils. In trials at Mettumaradur (Tamil Nadu) a crop of *dhaincha*, raised in the soils after preliminary correction of soil alkalinity using gypsum as an amendment, proved effective in improving soil fertility and increasing paddy yields up to 33.6 q per ha in the treated area where no crop grew before.

Protein content of cereal crops also increases when grown in association with legumes in suitable proportions.

To derive maximum benefit by growing legumes for increasing yields and high nitrogen content, and building soil fertility and reclamation (*i*) the seeds of the legumes should be inoculated with relevant strains of rhizobium suited to the locality, and (*ii*) lime or phosphorus or minor elements like boron and copper should be applied, as and when required, as fertilizers or for correcting soil acidity. The right kind of bacteria must be present in the soil for each leguminous crop. When a legume is grown for a number of years, the right type of nodule bacteria usually gets established in the soil, unless it is destroyed by bacteriophage or parasitic fungi. This can be avoided by inoculating the legume seed at planting time with nitrogen-fixing bacteria, thereby ensuring that the seedlings are exposed to the right kind of nitrogen-fixing bacteria early in the growing season. Where the soils are very poor in nitrogen there should be addition of adequate amount of nitrogen to meet the crop requirements till the nodules are well established, i.e., usually up to six weeks from the date of germination. The use of legume inoculants has given consistent increase in yields in different soils all over the world; when grown for the first time, 25-60 per cent increase in the yield of berseem and other legumes was obtained, and in some cases the increases were as high as 200 per cent.

In India, bacterial cultures specific for common leguminous food, fodder, and green-manure crops including *arhar* (*Cajanus caian*), cowpea (*Vigna sinensis*), *mung* (*Phaseolus aureus*), *urid* (*Phaseolus mungo*), horse gram (*Dolichos biflorus*), *khesari* (*Lathyrus sativus*), gram (*Cicer arietinum*), pea (*Pisum sativum*), lentil (*Lens culinaris*), groundnut (*Arachis hypogaea*), soybean (*Glycine max*), berseem (*Trifolium alexandrinum*), lucerne (*Medidago sativa*), *dhaincha* (*Sesbania sesban*) and sunnhemp (*Crotalaria juncea*), are available from the Division of Microbiology, I.A.R.I., New Delhi, Agricultural College, Poona; Bose Institute, Calcutta; Punjab Agricultural University, Hissar; University of Agricultural Sciences, Bangalore; Agricultural Research Institute, Anand; and a few other laboratories.

CULTURE

Method of preparation of cultures

Isolation of pure culture of legume bacteria: A six to eight-week-old, vigorously growing legume plant is carefully uprooted without injuring its nodules or the roots. In case of the legume fodder crops, the second cutting stage and in others the second year of sowing is preferred. The young, fresh and healthy nodules are usually pinkish in colour and oval in shapes. They are separated by cutting a portion of the root on each side of the nodule to avoid injury to it and prevent the sterilizing liquid from entering the nodule. After washing the separated nodules carefully, they are placed in a sterilized test-tube containing 10 ml (1 : 1,000) mercuric chloride (HgCl) and kept immersed for five minutes, taking care that no air bubbles stick to them. The solution is then decanted and the nodules (in the test-tube) are washed about six times with sterile water and crushed under water with a sterile glass rod. The suspension contains the organism. These are now ready for culturing on yeast-extract-mannite agar medium, which is composed of the following ingredients:

Mannite 10 g, K_2HPO_4 0.5 g, $MgSO_4$ 0.2 g, NaCl 0.1 g, $CaCO_3$ 3 g, Difco yeast extract 1 g, agar 14 g, and distilled water 1,000 ml.

The agar is poured into some test-tubes and allowed to settle in slants. A few test-tubes with molten agar are transferred to a water-bath maintained at 45°C and the nodule suspension is added by transferring a loopful of the nodule suspension to one of the tubes by means of a sterilized platinum loop. The agar is mixed thoroughly by keeping the tube in between the hands and moving the hands forwards and backwards.

The contents of the tube are then poured into a sterilized Petri-dish and allowed to set uniformly by rotating the dish to and fro in a clockwise direction. Some drops will be left in the tube; one of these may be transferred to another unused tube and the process repeated till the third and the fourth dishes are ready. Temperature should be 45°C throughout. When the agar solidifies, the dishes are inverted and transferred to an incubator kept at 30°C. Since the original inoculation is diluted in the successive tubes, clear isolated colonies are expected to grow in some of the plates. Usually the colonies appear after four to five days.

They are usually smooth, raised and slimy, and resemble shining water-drops.

Testing the purity and efficiency of the culture: The contaminants associated with root nodule organisms are *Bact. tumefaciens* (*Agrobacterium tumefaciens*) and *Bact. radiobacter* (*Agrobacterium radiobacter*). They can be detected by the different behaviour on different synthetic media.

Congo-red agar medium offers a means of detecting *Bact. tumefaciens* since it produces deep-red colonies in contrast to the whitish colonies of the true rhizobia. *Bact. radiobacter* and crown gall organism absorb the colour comparatively less but still it is more than true rhizobia. Many of the soil bacteria markedly absorb the colour. The other contaminant, *Bact. radiobacter*, can be detected by drawing streaks on Hoffer's alkaline medium (pH 13), in which rhizobia do not grow whereas *Radiobacter* does.

Yeast extract Congo-red medium (*Capping method*) : Plate with the organism as usual on yeast extract mannite agar. After the agar sets in the plates, pour 5 to 10 ml of sterilized Congo-red medium on it at 45°C and allow it to form a thin layer. The *Rhizobium* colonies will be comparatively whitish. The Congo-red medium is prepared by adding 10 ml of 1:400 aqueous solution of the dye to ordinary yeast-extract medium containing 1 per cent agar.

Hoffer's alkaline medium: The ordinary yeast-extract medium and N|5 NaOH is sterilized separately; 10 ml of the medium are poured with a sterilized pipette into the cell used for determining pH and a known quantity of N/5 NaOH is added till the pH is 13. The medium is now poured into Petri-dishes and after it sets in streaks are drawn with the culture. If no growth appears *Bact. radiobacter* is absent.

Milk tests: These are of two types:

Ordinary milk: In each of the sterilized test-tubes 10 ml of skimmed milk is poured and sterilized at 100°C for half an hour on three consecutive days.

Litmus milk: One gram of Asolitmin in 100 ml of distilled water is boiled for 10-15 minutes and filtered, and later autoclaved at 6.8 kg pressure for 20 minutes. Then, 10 ml of the solution is added to 100 ml of skimmed milk and the mixture shaken thoroughly. The mixture (10 ml) is poured into sterilized test-tubes.

Both the tubes, when inoculated with a loopful of the culture, reveal chocolate colour in presence of *Radiobacter* in ordinary milk and brown colour with a slimy ring in the presence of litmus milk.

Efficiency of rhizobium: The organisms are considered efficient when they are able to: (*a*) establish in competition with the organisms already present in the soil; (*b*) form healthy and abundant nodules; and (*c*) fix nitrogen as judged by increased yield and uptake of nitrogen by the inoculated crop, as compared with the uninoculated one. Since phosphate plays an important role in the nutrition of leguminous plant in all tests with legume cultures; adequate amount of phosphate must be made available to the crop. Normally, four replications and the following treatments are to be maintained: (*a*) control (uninoculated), (*b*) culture 1, (*c*) culture 2, and (*d*) KNO_3 treatment at the rate of 9 kg N. The increase in yield and nitrogen recovery owing to bacterial inoculation and KNO_3 treatment over control show the extent of benefit attributable to inoculation and relative efficiency of the inoculants. The method of inoculation consists of inoculating the seeds with pure strain of *Rhizobium* from a slant or with a soil culture following the procedure described below. Then the seeds are dried in the shade and sown. Observations recorded include nodulation, yield of the crop and nitrogen recovery by the crop.

Soil culture. The soil medium is prepared with the following materials:—

Soil (1,000 g), sugarcane (10 g), hay of the legume (10 g), K_2O (0.5 g), water 120 ml (one-third to one-half water-holding capacity) and $CaCO_3$ 5 per cent (only in soils low in lime).

The tins are packed with 400 g of soils in each case after the above ingredients are mixed. The tins with soil are sterilized at 9 kg pressure for two hours for two consecutive days and again on the fourth day.

The culture medium is distributed at the rate of 150 ml in 500 ml flasks and sterilized at 6.8 kg pressure for half-an-hour. Each flask is inoculated with suspension from the slant of one tube having culture of 24-hour growth. The flasks are shaken in the shanker for periods varying from 24 to 72 hours depending on the generation time of the organisms. In *Rhizobium* specific for soybean and the usual pulse crops, shaking for 72 hours is recommended. In each tin 10 ml of the cultures so obtained are added and contents of the tins are thoroughly shaken. The tins are incubated at 28° C for seven days. The bacterial count in the soil culture should be at least 100 million per 1 g of soil culture. In quick growing organisms, it may reach a level of 300 million per 1 g of soil culture within a period of seven days. To inoculate seeds for one hectare of land 990 g of the culture are sufficient.

Instructions to use the soil culture: 1. Prepare *gur* solution by dissolving 150 g *gur* in 1 kg of water. Boil for half-an-hour and cool.

2. Add 400 g of soil culture to the gur solution and mix thoroughly.

3. Mix seeds sufficient for one hectare of land thoroughly in the suspension of the culture in *gur* solution and allow it to remain there for about 15 minutes.

4. Take out the seeds, spread them on a clean cloth and allow them to dry in shade for an hour.

The seeds are now ready for sowing.

Variation in the efficiency of different rhizobia: Efficiency of different strains of rhizobia varies, depending upon the capacity of the *Rhizobium* to influence the percentage of water stable soil aggregates in the synthesis of B group vitamins, like vitamin B_{12} and other growth-promoting substances, in increasing the yield and recoveries of nitrogen by the legume, and the yield of succeeding cereals.

To obtain bacteria with induced activity the seeds of clover are put in soil rich in nitrogen. Plants are grown for a month and later transferred to soils poor in nitrogen. Here they fix nitrogen from the air in large amounts; thus the bacteria are artificially forced to fix more nitrogen from the air and supply it to the crop. The selection of bacteria by this method is more effective. Nodule bacteria of clover multiply in the soil at 2°–40° C. They are not killed at –27° C but remain viable. According to the Soviet standards, each gram of nitrogen for quick-growing bacteria should contain not less than 300×10^6 cells. A certain percentage of contamination (not exceeding 10) is allowed.

In India, while the cereal crops cover an area of 90 million hectares, the leguminous crops which include gram, *arhar*, pea, *urid*, *mung*, soybean, groundnut, berseem and lucerne cover an area of 30 million hectares. Since the latter can utilize atmospheric nitrogen through agency of *Rhizobium* specific for the crops when proper soil conditions and phosphate availability to crop are assured, the

use of these bacterial inoculants are recommended to utilize the gaseous nitrogen. The gaseous nitrogen is present to the extent of about 80,000 tonnes in the air that overlies each hectare.

Some of the results obtained with *Rhizobium* cultures specific for different crops are shown in Tables 2, 3, and 4.

In the U.S.A. about 46.5 million hectares are under legumes; 42 per cent of the legume seeds planted are inoculated. In some of the areas, the soils abound in effective root nodule bacteria. In spite of the fact that in the U.S.A. about 5 million tonnes of nitrogenous fertilizers are produced, they manufacture about 25 million bushel-size units of *Rhizobium* cultures costing about 7.5 million dollars for treating the leguminous food and fodder crops.

TABLE 40. RHIZOBIUM INOCULATION TESTS WITH SOYBEAN, *URID* AND COWPEA

(Field Experiment, Kanpur)

Crop	Treatment	Yield of grains (kg/ha)	Increase over control (per cent)
Urid	Uninoculated	1,775	—
	Inoculated	1,950	10
	Uninoculated + P_{45} *	1,825	—
	Inoculated + P_{45}	2,090	15
Soybean	Uninoculated	950	—
	Inoculated	1,088	15
	Uninoculated + P_{45}	1,320	—
	Inoculated + P_{45}	1,808	36
Cowpea	Uninoculated	1,775	—
	Inoculated	1,650	–7
	Uninoculated + P_{45} *	3,180	—
	Inoculated + P_{45}	3,270	3

* Superphosphate at the rate of 45 kg P_2O_5 per hectare.

TABLE 41. SUMMARY OF FIELD EXPERIMENTS ON LEGUMES INOCULATED WITH *RHIZOBIUM*

Place	Crop	Number of field experiments conducted	Number of experiments resulting in significant increase
Bihar			
Kanke	Soybean	2	2
	Mung	3	3
	Urid	1	1
Purnia	Gram	3	1
	Khesari	3	1
	Kalai	3	1
	Pea	1	1
Sabour	Soybean	3	2
Bakragunj	Pea	1	1
Patna	Gram	2	—
Madras	Sunnhemp	1	1
	Arhar	1	1
	Cowpea	1	1
	Mung	1	—
	Urid	1	—
Delhi	Groundnut	1	1
	Gram	1	1

The need for production and distribution of *Rhizobium* cultures in this country for the leguminous food and fodder crops is all the more important in view of the shortage of nitrogenous fertilizers and this aspect is receiving immediate attention at the Division of Microbiology, Indian Agricultural Research Institute, New Delhi.

Another important finding in which bacterial inoculation is likely to be useful is the treatment of the seeds of cereal crop with *Azotobacter* or a combination of *Azotobacter* and *Rhodopseudomonas capsulatus* (a photosynthetic nitrogen-fixing organism) for

TABLE 42. PERFORMANCE OF SOYBEAN VARIETIES AS INFLUENCED BY INOCULATION* AND FERTILITY LEVELS IN 1967 (JABALPUR)

Fertility levels (kg/ha) N	P	K	Inoculum	BRAGG Yield (kg/ha)	BRAGG Protein (per cent)	BRAGG Oil (per cent)	CLARE Yield (kg/ha)	CLARE Protein (per cent)	CLARE Oil (per cent)
10	40	20	(a) Inoculated	3,220	43.1	22.6	2,419	43.3	21.9
			(b) Uninoculated	2,075	43.1	22.6	1,428	40.5	23.2
40	40	20	(a) Inoculated	3,209	43.0	22.3	2,771	43.6	21.4
			(b) Uninoculated	2,412	43.4	22.9	1,633	39.2	22.6
10	160	20	(a) Inoculated	3,292	43.2	22.3	2,622	44.5	20.7
			(b) Uninoculated	2,247	42.1	22.9	1,671	44.7	20.9
40	160	20	(a) Inoculated	3,318	43.5	22.3	2,973	44.3	21.1
			(b) Uninoculated	2,798	43.1	22.9	1,848	44.0	21.6
10	40	80	(a) Inoculated	3,029	42.7	23.0	2,481	43.4	21.3
			(b) Uninoculated	1,485	40.1	23.6	948	35.9	24.9

* 'Dixie' culture from the U.S.A.

increasing crop yields (Tables 5-7). Some of the important points to find out are whether the introduced organism is established in the rhizosphere of the plants and whether under unsterilized soil conditions real benefit is accrued to the crop by way of supply of mineral nutrients. This aspect was investigated and it was observed that the introduced organism *Azotobacter* was established in the rhizosphere of crops (Table 8).

TABLE 43. EXPERIMENT WITH *AZOTOBACTER* UNDER UPLAND CONDITIONS, FIELD EXPERIMENT AT C.R.R.I., CUTTACK (YIELD OF GRAIN IN KG|HA, PADDY VAR. 'PTB.10')

Treatments	1959-60	1960-61	Mean
M_0T_0	1,170	2,028	1,599
M_0T_1	1,187	1,856	1,522
M_1T_0	1,994	2,107	2,051
M_1T_1	2,520	2,311	2,415
M_2T_0	1,318	1,996	1,657*
M_2T_1	1,325	2,130	1,728
		C.D. at 5%	117

M_0	Unmanured control
M_1	33.6 kg N|ha as ammonium sulphate + 33.6 kg P_2O_5|ha as superphosphate
M_2	33.6 kg P_2O_5|ha as superphosphate + 33.6 kg K_2O_5|ha as potash sulphate
T_0	Uninoculated
T_1	Inoculated

In paddy crop, treatment with urea at 40 kg N per ha coupled with inoculation with *Beijerinckia* gave significantly superior yield than the control, whereas 40 kg N per ha applied in the form of urea alone was not as effective. Further, treatment with urea at 40 kg N per ha + *Beijerinckia* inoculation did not significantly differ from urea at 80 kg N ha (Table 9). Beneficial effects of *Azotobacter* inoculation have been traced among other things owing to synthesis of growth-promoting substances. The amount of vitamin B compounds synthesized by *Azotobacter* and by yeast is indicated in Table 10. In phosphate solubilizing organisms, the amount of P_2O_5 taken up by the crop considerably increased (Table 11).

TABLE 44. INOCULATION WITH *AZOTOBACTER* NUMBER OF FIELD TRIALS

Place	Number of crop experiments conducted		Number of experiments showing significant increase
Delhi	Wheat	3	—
Alluvial soil	Peas	3	1
	Cabbage	1	1
Cuttack	Paddy	2	2
Anand	*Jowar*	3	2
Hyderabad	Paddy	1	1
Total		13	7

TABLE 45. YIELD OF WHEAT 'NP 876' DUE TO BACTERIZATION WITH *A. CHROOCOCCUM* AND *RHODOPSEUDOMONAS CAPSULATUS* (FIELD TRIAL 1966)

Treatments	Grain yield kg 33.4 m^2	Grain yield in kg|ha
Control	3.06	2,418
Urea at the rate of 44.84 kg N/ha	13.43	4,029
A. chroococcum	8.63	2,589
R. capsulatus	8.26	2,478
A. chroococcum and *R. capsulatus*	3.26	3,978
Urea and *A. chroococcum*	13.36	4,008
Urea and *R. capsulatus*	13.20	3,960
Urea, *A. chroococcum and R. capsulatus*	14.00	4,200

TABLE 46. FIELD EXPERIMENT (1966-67). NUMBER OF *AZOTOBACTER* PER G OF DRY SOIL AND RHIZOSPHERE OF WHEAT CROP

Treatments	Counts of *Azotobacter* per g of dry soil		
	Non-rhizosphere Mean	Rhizosphere Mean	R|S Ratio
Control (only basal dressing)	4,253	44,800	10.5
Urea (N)	5,080	41,000	8.1
Azotobacter (A)	50,500	68,933	1.3
Rhodopseudomonas (R)	48,366	63,333	1.4
A + R	67,666	308,166	4.5
N + A	31,666	55,333	1.7
N + R	31,250	24,733	0.9
N + A + R	57,066	55,333	1.07

TABLE 47. EFFECT OF *BEIJERINCKIA* INOCULATION ON PADDY YIELD. (Field Experiment)

Season	*Kharif* 1967
Variety	'Taichung Native 1'
Lay-out	Randomized Block Design
Replications	Four

Treatments	Average grain yield per plot in kg	Grain yield in kg|ha	Per cent increase over control
Control	0.889	2,871	
Beijerinckia	0.871	2,812	–2
40 kg N	1.140	3,681	28
40 kg N + *Beijerinckia*	1.417	4,575	59
80 kg N	1.498	4,837	69
80 kg N + *Beijerinckia*	1.561	5,040	76
120 kg N	1.615	5,215	82
120 kg N + *Beijerinckia*	1.462	4,721	64
C.D. at 5% level for treatments	0.291	940	

N applied as urea (kg|ha)

Notes

1. Urea at 40 kg N/ha + *Beijerinckia* was significantly superior to the control whereas 40 kg N/ha alone was not.
2. Urea at 40 kg N/ha + *Beijerinckia* inoculation did not significantly differ from urea at 80 kg N/ha alone.

TABLE 48. AMOUNT OF VITAMIN B COMPOUNDS SYNTHESIZED BY AZOTOBACTER AND BEER YEAST μG PER G OF DRY CELLS

	Thiamin	Riboflavin	Nicotinic acid	Biotin	Pantothenic acid
Azotobacter	96	304	480	4.23	184
Beer yeast	40	50	500	2.00	50

The number of field experiments conducted in different parts of the country under different soil and climatic conditions and the number of experiments showing significant increases in crop yields when the seeds are treated with phosphobacterin are shown in Table 11.

GROWING OF MICRO-ORGANISMS ON MASS SCALE

Until recently the surface method of producing bacteria on solid media or in a shallow layer in liquid media was followed. This method required a large surface area and could not be easily subjected to automation or mechanization. Presently the 'deep' cultivation method is followed. It provides very favourable conditions for multiplication of bacteria. The micro-organisms are inoculated into the nutrient medium containing all the necessary substances. The medium is aerated for facilitating multiplication of bacteria. The reaction vessels (tanks) in the factory producing the bacterial fertilizers are of 1,000-litre capacity. The 'deep' cultivation method has very pronounced advantages to its credit, especially in the increased number of cells (Table 13).

One of the essential factors in the deep-cultivation method is sufficient supply of air in the medium. The air should be atomized and should be distributed evenly in the entire tank. Another important condition is the selection of nutrient medium. It must not only meet the requirements of microbes in respect of nutrients but also facilitate quick multiplication and formation of spores, e.g. in B. *megatherium*. The nutrient medium is sterilized in the tanks if the capacity of the latter does not exceed 1,000 to 3,000 litres.

TABLE 49. UTILIZATION OF ADDED P_2O_5 BY WHEAT (1964-65) AS PER CENT (Mean of Four Replications)

Treatment	With FYM		Without FYM	
	S_1	S_2	S_3	S_4
Uninoculated Control	6.81	4.24	6.66	4.96
Inoculated with P.B.	8.92	5.31	7.70	6.67
Inoculated with I_2	6.18	5.51	8.87	7.09
'F' test	Sig.	Sig.	Sig.	Sig.
SEM ±	0.533	0.533	0.533	0.533
C.D. at 5% ±	1.53	1.53	1.53	1.53

S_1 — Soil + FYM + ammonium sulphate + superphosphate
S_2 — Soil + FYM + ammonium sulphate + apatite
S_3 — Soil + ammonium sulphate + superphosphate
S_4 —Soil + ammonium sulphate + apatite

TABLE 50. PHOSPHOBACTERIN INOCULATION

Place	Crop	Number of Field Trials	Percentage increase	Number of experiments showing significant increases
Delhi Alluvial soil	Berseem	6	10-20	4
	Maize		*20-30	1
Karnal Alluvial impregnated with salt	Wheat	3	*16-37	1
	Maize	2	14.C	1
	Paddy	3	—	1
Pusa (Bihar) Calcareous soil	Gram	1		
	Urid	3	*16-19	Nil
	Wheat	1	—	Nil
	Maize	1	—	Nil
	Paddy	1	—	Nil
Wellington Acid soil	Potato	1	—	Nil
	Wheat	1	—	Nil
Nagpur Black cotton soil	*Arhar*	1	—	
Indore Black cotton soil	Paddy	2	*19-31	1
Rajendranagar Hyderabad	Paddy	5	*12-14	1
Simla Acid soil	Wheat	1	—	Nil
Bapatla	Paddy	1	—	Nil
Ranchi Acid soil (Limed)	Soybean	1	—	Nil
	Groundnut	2	—	Nil
		36		10
Acid or calcareous	soil experiments	(—) 13		(—) 1
		23		9

* Percentage increase over corresponding uninoculated in different treatments.

TABLE 51. ADVANTAGE OF 'DEEP' CULTIVATION METHOD OVER SURFACE METHOD OF PRODUCING BACTERIA

Bacteria	Ordinary method	'Deep' cultivation method
Nodule bacteria	20–50 × 10^6 per cc	2,000 × 10^6 to 4,000 × 10^6 per cc
Azotobacter	10–15 × 10^6 per cc	1,000 × 10^6 to 1,500 × 10^6 per cc
Phosphobacter	All in liquid medium	1,000 × 10^6 to 2,000 × 10^6 per cc

A laboratory submerged cultivation unit with a capacity of 100 litres costs about Rs 20,000. The bacterial mass is concentrated by centrifuging at a speed of 9,000–11,000 revolutions per minute. The centrifuge delivers 40 litres of bacterial mass per hour. The cost of the centrifuge is about Rs 20,000. The reaction vessel of 100-litre capacity gives 1 kg of phosphobacterin paste containing 50 per cent moisture when used for producing phosphobacterin. The cells are dried by lyophilizing them in vacuum at 10–3 mm Hg at low temperature of –20° to –25°C. Dry CO_2 is used for the purpose.

Dose of air in deep cultivation. The ordinary dose of air is one litre per litre of medium in one minute. This amount is subject to composition of the nutrient medium. Media with plant extracts form foam when micro-organisms are grown; this can be avoided by addition of a small amount of sunflower oil. Sometimes, the development of bacteriophage is observed and it contaminates the surrounding atmosphere. To prevent it, 5 per cent formaldehyde is used for systematic disinfection of the plant premises. When phase development is observed, the strain of bacteria should be replaced by a phase resistant strain.

Use of inoculum with deep-cultivation method. Dry inoculum is added to a liquid medium in a flask provided with a shaker. When reaction starts and the bacteria multiply the contents are transferred to the tank.

When soil culture is prepared for legume inoculation in clay and acidic soils, sand and chalk are added for making up the structure and checking acidity. The pH should be 6.8 and the moisture should be adjusted to 60 per cent water-holding capacity. In bottles of half-litre capacity 40 per cent water-holding capacity is made up in the soil (0.5 kg) and they are sterilized at double the atmospheric pressure (120°C) for two hours. In the U.S.S.R. 30 cc of culture are added in each bottle if the organisms are grown in flasks and the bottles are incubated for seven to eight days. On the other hand, if the culture from the aeration reactor is added, lesser quantity of culture can be added, since each cc contains several million cells. The bacterial count is taken after two days. The soil culture usually contains 300×10^6 and 100×10^6 cells in the fast- and slow-growing organisms respectively.

Inoculation with Azotobacter or phosphobacterin. The important point of bacterization with *Azotobacter* (a non-symbiotic nitrogen-fixing organism) and phosphobacteria (Phosphorus-solutioning organisms) is that the seeds are to be bacterized with a heavy population. In the U.S.S.R., *Azotobacter* and phosphobacteria have been produced for 3 and 14 million ha of land respectively.

ALGAL INOCULANTS

By and large, the soil algal community is found on or just below the soil surface, although many forms have been recorded from considerable depths. The deep-growing community is largely composed of surface growing forms that are washed down into the soil by percolation of rain water or irrigation water, and by regular cultivation of the fields in some cases. Since these forms are essentially phototrophic, their contribution beneath the illuminated zones of the soil towards soil fertility largely depends on the utilization of their own reserves or of the organic matter present. Thus, in the deeper layers, they may not increase the fertility substantially, although they may probably add to the organic of the soil. Their importance in soil economy lies chiefly in their growth on the soil surface where photosynthesis is possible.

Most of these algae are cosmopolitan in distribution, although differences in specific composition and quantitative characterization do exist. To find out the inherent basic algal population in different soils, enrichment cultures are generally used.

In the rice fields of Uttar Pradesh and Bihar occur a dominant and widespread nitrogen-fixing algal community of blue-green algae, constituted mainly by *Aulosira fertilissima* intermingled with *Anabaena ambigua*, *A. fertilissima* and *Cylindrospermum gorakhpurense*. Singh's in 1942 and 1961 and author's observations in rice soils from the States of Tamil Nādu and Kerala reveal ubiquitous occurrence of *Aulosira fertilissima* which seems to have a great affinity for conditions prevailing in rice fields. In 1949 Gonzalves and Gangla, on the basis of their study of the algae of soils of rice fields from Bombay, correlated the algal growth with the physical and chemical properties of the soils such as texture, moisture, moisture-retaining capacity, calcium content and pH.

The blue-green algae show an overwhelming preponderance over the other classes of algae in India as against the temperate soils where the reverse is the case.

Order and Family	Species able to fix nitrogen
Chroococcales	*Chloroglea fritschii*
Nostocales	
Nostocaceae	*Anabaena ambigua*, *A. cylindrica*, *A. fertilissima*, *A. humicola*, *A. naviculoides*, *A. oryzae*, *A. variabilis*, *A. azollae*, *Anabaena* spp., *Anabaenopsis circularis*, *Cylindrospermum maius*, *C. gorakhpurense*, *C. licheniforme*, *C. sphaerica*, *Nostoc commune*, *N. paludosum*, *N. punctiforme*, *N. muscom* and *Nostoc* spp.
Microchaetaceae	*Aulosira fertilissima*
Rivulariaceae	*Calothrix brevissima* and *C. parietina*
Scytonemataceae	*Tolypothrix tenuis*
Stigonematales	
Stigonemataceae	*Mastigocladus laminosus* and *Stigonema dendroideum*

BLUE-GREEN ALGAE CAPABLE OF FIXING NITROGEN

The principal genera containing maximum number of nitrogen fixing species are *Nostoc*, *Anabaena* and *Cylindrospermum*. The nitrogen-fixing blue-green algae, known so far are listed at page 241.

The utilization of these organisms in the general agricultural practices involves the following considerations:

(*a*) growth and general physiology of these organisms; (*b*) strain variation and nitrogen-fixing capacity; (*c*) strain competition; (*d*) nature and production of extra-cellular substances; (*e*) mass culturing and seeding material; and (*f*) their role in the rice fields.

Growth and general physiology. All the nitrogen-fixing blue-green algae except a strain of *Nostoc punctiforme*, are capable of phototrophic growth in purely inogranic media, although a few are also capable of heterotrophic growth. In this condition the growth and nitrogen fixation are lower.

The blue-green algae utilize a variety of nitrogen sources, besides the free nitrogen from the atmosphere. They prefer usually neutral or slightly alkaline conditions, though many of them may also be encountered in the acid rice field soils, as in Kerala. Molybdenum is an important element necessary for their growth. Calcium, sodium, boron and cobalt have also been found important in this respect. No requirement of organic growth factors appears to have been demonstrated for a nitrogen-fixing blue-green algae.

Strain variation. There are great differences in the amount of nitrogen fixed by various genera, and sometimes by the same species from different localities (Tables 52, 53).

The influence of genetic constitution is an important factor which determines the relative capacity of blue-green algae to fix nitrogen.

Nature and production of extracellular substances. The important factors in regulating the extent and accomplishment of increased soil nitrogen by the algal activity are: (*a*) relative efficiency of their nitrogen-fixing capacity, (*b*) their carbohydrate status; (*c*) rate of excretion of soluable nitrogenous substances and their availability to the crop plants; and (*d*) the soil and root environment. About 50 per cent of the total nitrogen fixed by these organisms appears in the medium in soluable form. The deficiencies of potassium and iron in the medium have been found to markedly increase the liberation of extracellular nitrogen by Venkatraman in 1960, whereas higher concentrations of nitrate in the medium inhibit the liberation significantly. This was reported by Venkataraman in 1961 and Henriksson in 1957. This should be borne in mind while applying these algae to the fields along with commercial nitrogeneous fertilizers.

TABLE 52. EXTENT OF NITROGEN FIXATION BY VARIOUS BLUE-GREEN ALGAE (SINGH, 1961)

Algae	Period of incubation (days)	Nitrogen fixed (mg)
Cylindrospermum sohaerica (Venkataraman *et al.*, 1959)	55	3.92/75 ml
C. gorakhpurense (Singh, 1942)	45	5.0/100 ml
Anabaena ambigua (Singh, 1942)	45	5.6/100 ml
A. fertilissima (Singh, 1942)	45	6.7/100 ml
A. oryzae (De, 1939)	60	4.5/100 ml
A. variabilis (De, 1939)	60	5.7/100 ml
A. naviculoides (De, 1939)	60	3.6/100 ml
Stigonema dendroideum (Venkataraman, 1961d)	20	3.24/100 ml
Nostoc sp. (Venkataraman, 1960b)	30	2.2/100 ml
Anabaena azollae (Venkataraman, 1962b)	30	3.49/100 ml

The extracellular products may be ecologically important in many ways; those liberated are directly utilized by other organisms, thus, short circuiting the nutrient cycle, or some of the extracellular enzymes may play a part in the breakdown of organic substances. They may also be responsible for determining the existence and abundance of a particular form in a given en-

TABLE 53. VARIATION IN THE NITROGEN-FIXING CAPACITY OF NOSTOC FROM DIFFERENT LOCALITIES
(VENKATARAMAN, UNPUBLISHED)

Localities	Period of incubation (days)	Nitrogen fixed (mg)
Chandigarh, Punjab	30	1.3/100 ml
Calcutta, West Bengal	30	0.96/100 ml
Okhla, Delhi	30	1.00/100 ml
Gopalasamudram, Tamil Nadu	30	0.92/100 ml

vironment. Some of the extracellular products of algae have chelating properties. The filtrates of an endophytic *Nostoc* strain have given some indication of presence of some thermolabile growth promoting substances. While the extracellular nitrogenous substances are composed of complex polypeptides in some cases, as in *Calothrix breissima* and in a *Nostoc* strain, considerable amounts of free amino acids like aspartic acid, glutamic acid and alanine have been observed. Recently, Henriksson in 1961 reported that polysaccharides and vitamins belonging to B-complex (thiamine, riboflavin, nicotinic acid, pantothenic acid and biotin) are excreted by the *Collema nostoc*.

In 1967, Venkataraman and Neelakantan recently showed that the beneficial effect of blue-green algae on rice plants was more because of Vitamins and auxins synthesized and supplied by these algae to the crop than the nitrogen fixed by them. This accounts for the additional effect of algae even in presence of high-level nitrogenous fertilizers.

Mass culture and seeding material. The two main considerations in the utilization of these algae in our agriculture are: (*a*) growing the algae in abundance (mass culture), and (*b*) preserving the algae for 'seeding' purposes. In Japan, the three most commonly used techniques for mass culturing are: (*a*) a stirring culture in a tank having glass windows through which the culture is illuminated from the outside, (b) a closed circulation culture using a flat tube of vinyl sheeting, and (*c*) culturing on the moist surface of fine porous volcanic gravel. The 'open-bubbling' system of Watanabe *et al.* (1959) has been found to yield about seven tonnes of alga a year. This would be sufficient for inoculating 304 ha of paddy fields for changing its microflora.

The preservation of these algae in a fresh state is equally important. Watanabe in 1959 cultured and preserved these algae on moist volcanic graval (*Kanumatsuchi*) and found this method preferable to the lyophilization technique. The moist surface of the fused magnesium phosphate fertilizer has also been found to be a good substratum for growing these algae with the additional advantage of the magnesium phosphate being utilizable by the crop plants. In 1961 Venkataraman developed a 'dry sand' seeding material, where ordinary sand is washed several times with distilled water and soaked in a nitrogen-free medium and sterilized. The sand is mixed with concentrated algal suspension and gradually dried in the sunlight. The dried sand thus obtained can be stored in polythene bags or bottles and handled freely. Such dried material may retain its reviving capacity unimpaired for well over two years. If extensive trials prove successful, it may be economical for preparing the seeding material in our country.

To make it more economical and practical, open-air soil culturing was developed simulating the rice-field conditions. Large trays of 2 m × 1 m were layered with 5-cm soil and kept water-logged. Prior to seeding, the trays were sprinkled with lime to promote the growth of inoculated algae. Suitable strains of algae were inoculated and the trays were kept open in the sunlight. On bright sunny days, the entire soil surface get covered with a thick algal mat within a week. The water is allowed to dry and the algal flakes, which crack, are collected and used for inoculation purposes. The advantages of this simple procedure are : (*a*) large amount of algae can be prepared with least cost, (*b*) this principle can be adopted in the farmer's field itself, and (*c*) this method helps the organism to adapt to the soil.

Role of blue-green algae in rice fields. The condition of rice fields in India may be clearly distinguished into three periods: (*a*) the water-logged period from transplantation to harvest time; (*b*) the dry period after harvest, and (*c*) the desiccation period during which the soil temperature frequently exceeds 50°C. During the latter periods the algae remain dormant and their activity is almost nil. The available evidence shows that under water-logged rice-field conditions the nitrogen fixation is essentially an algal process.

The appearance of an abundant growth of algae in water-logged rice fields is a very common phenomenon in the tropics, and the fertility of the rice fields in the tropical countries may be at least partly ascribable to the activity of these algae. Unfortunately little information is available on the magnitude of nitrogen fixed by these organisms in the rice fields in India.

Prasad in 1949 reported that the amount of nitrogen added to rice fields in South Bihar due to the activity of these algae was about 14.5 kg per ha after harvesting the crop. In 1950, De and Sulaiman, on the basis of extensive potculture experiments with rice plants over five years, with or without these algae, found that during the first two or three years the yields of rice crop in the presence and absence of algae were not much different, but thereafter the former showed a progressive increase and the latter a similar decrease. In the fourth and the fifth year the yields in the presence of algae were much higher than those in its absence, and the amount of nitrogen in the soils with algae showed considerable increase in contrast to soils lacking algal growth of this amount.

Nitrogen fixation has been found to be greater in the presence of the crop than in its absence. This was reported by De and Sulaiman, 1950; De and Mandal, 1956. This is attributed to the increased supply of carbon dioxide resulting from respiration and decomposition of roots of the plants. In the cropped but unfertilized soils, fixation varied from 15.5-49.7 kg N per ha, and the application of 67.2 kg P_2O_5 per ha (superphosphate) stimulated nitrogen-fixation only in relatively poor soils. De and Sulaiman in 1950 observed that the addition of phosphates to rice soils, whether as potassium phosphate or as calcium phosphate, stimulated the nitrogen-fixation by algae. On the other hand, potassium or magnesium sulphates when applied singly had a depressing effect; this was not noticeable when the two were used in combination with phosphates. The addition of molybdenum also enhanced fixation. Phosphate, calcium and molybdenum supplies appear to be important limiting factors for the growth and nitrogen fixation by blue-green algae in certain rice-field soils.

Recently, it has been found that the nitrogen fixed by the blue-green algae is available to rice plants and that it is possible to grow rice with no nitrogen other than that fixed from the air by these algae.

Singh in 1961 performed pot-culture experiments and field scale trials with *Aulosira fertilissima.* The method of inoculation adopted was broadcasting the powdered stratum of the algae containing numerous spores mixed with 1 kg of lime on the surface of the puddled soil before transplantation. The results obtained by him are given in Table 54.

In Japan, Watanabe and co-workers reported increased growth of rice plants in both water and pot cultures. In water cultures inoculated with *Tolypothrix tenuis,* the lengths of the leaves were greater than those in the control by an average of 17 per cent and the number of ears by 30 per cent.

As a result of applying *Tolypothrix tenuis,* the yield of rice increased by 2.7 per cent in the first year, 8.4 per cent in the second year, 10.1 per cent in the third year and 21.8 per cent in the fourth year on an average of 11 fields. In one field, the inoculation with the algae was almost similar to that of manuring the field with 158 kg of ammonium sulphate per hectare as the additional fertilizer. The inoculation of paddy fields was performed during June–August (this period extends from about a month before to nearly a month after the 'bedding-out' of young rice plants) by seeding with the culture containing 2–10 kg of algae (dry weight) per hectare. Before seeding, water in the rice field was sprinkled with lime-powder which was effective in suppressing the growth of other algae and at the same time lowered the acidity of water to a favourable level.

In 1968, Datta and Venkataraman reported that besides introducing a specific nitrogen-fixing blue-green algal strains into the fields it is also possible to increase the soil nitrogen content by strengthening the indigenous blue-green algal flora.

For the promotion of the indigenous soil algae, the regimen, recommended by Subrahmanyan *et al.* in 1964a, 1965b and Relwani and Subrahmanyan in 1963 consists of an application of 1,000 kg lime, 100 kg of superphosphate and 0.25 kg of sodium molybdate per hectare.

A recent field trial in a fertile tract showed an increase of 15.76 per cent in the grain yield owing to a combined application of algae, superphosphate (100 kg/ha) and sodium molybdate (0.25 kg/ha), over the application of the fertilizer mixture alone (Table 17).

TABLE 54. EFFECT OF ALGAE INOCULATION ON RICE PLANTS (FROM SINGH, 1961)

Experiment	Height of plants (cm)	No. of tillers per plant	No. of ear-heads per plant	Yield of paddy per plot (g)	Yield of paddy per ha (kg)	Per cent increase over control
Control	73	5	3.5	5.0	1,187	—
Pots (inoculated)	14	15	12.7	23.4	—	368.0
Fields (inoculated)	135	12	10.3	—	2,550	114.8

TABLE 55. EFFECT OF ALGAL INOCULATION ON THE GRAIN YIELD OF 'ASD. 5' IN CULTIVATOR'S FIELD AT VASUDEVANALLUR, TAMIL NADU

	Grain yield (kg/ha)	Per cent increase
Fertilizer mixture	6,453.43	—
Fertilizer mixture + algae	7,470.68	15.76

Recent experiments have also shown that high-yielding varieties of paddy like 'I.R. 8', 'T.N. 1' also favourably respond to algal inoculation (Tables 18, 19).

TABLE 56. RESPONSE OF HIGH-YIELDING PADDY VARIETIES TO ALGAL INOCULATION

Variety	Per cent increase in grain yield over control
'T.141'	11.8
'GEB.24'	14.8
'Asd.5'	15.7
'T.N.1'	27.5
'IR.8'	22.07

Nitrogen fixation by blue-green algae in other soils. The only studies on the role of blue-green algae in other cultivated soils, like sugarcane and maize fields and grasslands, were those of Singh in 1961. The growth of *Cylindrospermum licheniforme* is a striking feature on the soil surface of the sugarcane and maize fields of Uttar Pradesh and the alga has been shown to add 89.9 kg of nitrogen per hectare in about 75 days.

In many grasslands, under the thick cover of grasses, the soil surface is invariably covered by thick mats of blue-green algae and the thicker the grass cover, the better is the growth of these

TABLE 57. EFFECT OF ALGAL INOCULATION ON THE GRAIN YIELD OF 'IR 8'

	Pot (g/pot)		Field *(kg/ha)	
	− Algae	+ Algae	− Algae	+ Algae
PK (45:30)	3.96	5.83		
NPK (100:45:30)	13.90	24.90		
NPK (100:80:45)			3567.3	4007.4

*Conducted in a cultivator's field at Moradabad, Uttar Pradesh.

algae. If the grass cover is not subjected to grazing or cutting, these algae continue to grow and add nitrogen to the soil. In 1961, Singh showed that owing to the growth of *Cylindrospermum licheniforme* the total nitrogen content of the soil of the grasslands increased by 88.2 per cent and the total yield of grass by 202.7 per cent.

Bloom algae as manure. The luxurious growth of perennial and planktonic blue-green algae (*Microcystic*, etc.) in our tanks and ponds (water-blooms) can also be profitably used as manures in our general agricultural practices. Pot-culture experiments with a Coimbatore variety of sugarcane ('CO.421') have shown that these boom-algae can be used as green manure because of their high nitrogen and phosphorus contents besides other growth-promoting substances.

Reclamation of *usar* lands by blue-green algae. Reclamation of alkaline *usar* soils by blue-green algae depends mainly on water-logging of the soils, which can be achieved either during the rainy season or by irrigation. The field is divided into small plots and enclosed on all sides by earth embankment, thus converting them into small, shallow ponds. These operations are done before the commencement of rainy season. When these shallow plots become water-logged owing to rains, the blue-green algae make their appearance on the surface, and within a fortnight or so form a compact stratum and continue to grow as long as water remains. When the water dries up the algal material can be ploughed and the soil levelled for the second time. It will be possible to treat the soil in this manner two or three times a year. Sloping lands may be subjected to the principle of 'contour-farming' by Singh in 1961, where the field operations, like ploughing, planting, cultivation and harvesting, are done at right angles to the natural direction of the slope of the land. Contour-tillage interrupts or retards water flow, thereby reducing erosion and increasing water penetration into the soil, especially in combination with algae like *phosphorosiphon notarisii* and *Microcoleus chthnoplastes.* All these practices are usually supplemented by construction of bunds on the contours.

Nostoc commune and *Aulosira fertilissima*, which are powerful nitrogen-fixers, can be introduced where they do not occur naturally by sprinkling the algal power mixed with lime on moist surface of the *usar* soils. The algal material thus incorporated in the soils conserves organic matter, nitrogen, phosphorus, moisture and also converts the sodium clay into calcium type. The field experiments conducted with paddy('T.9')and sugarcane('CO.421') in rotation on such reclaimed soils confirm the advantageous effect of algae in the reclamation of the soil (Singh, 1961).

SEA-WEED AS MANURE

The sea-weeds are rich in potash, ionic sulphates, trace elements, growth substances and other essential elements required by the crop plants. Since most of the nitrogen in the sea-weeds is in the ionic form, the crop plants can readily absorb the whole amount. However, they are poor in phosphates; therefore, to obtain best results from sea-weed manures, they should be supplemented by phosphates.

The sea-weeds commonly used as manure are the brown algae and are rarely some red algae producing lime. Weeds for manure are either collected from drift (drift-weed) or cut from the rocks (rock-weed), and the harvested weeds are applied either directly to the land or made into a compost.

In the direct application method the weeds are normally spread on the agricultural lands till the water content is reduced. In the 'lazy-bed' method alternate layers of land are cultivated and left fallow and the sea-weeds are applied to alternate strips in the field. Similarly, the weeds can be applied as a top-dressing, a method found to be good for cabbages and clover. They are used in many countries for sweet-potatoes, groundnuts, potatoes, turnips, Swedish oats, and coconut and coffee plantations. In the direct application methods other manures may also be added.

In most places the direct application of sea-weeds is not practicable, since the availability of drift-weed is seasonal and hence, limited. Here, the sea-weeds are preserved in the form of compost, which may be prepared by placing the sea-weeds between layers of sea-sand and farmyard manure, or the weeds may be mixed with sheep manure and, buried until it is partly decayed. Similarly, sea-weed meal and ash also can be prepared, particularly when they are required to be transported to the interior regions.

In India, Chidambaram and Unny in 1947 studied the sea-weed compost of fish-offal and shark-liver sediments (15:3:4) at Krusadai Island, South India. The analysis showed that the compost had 2.4 per cent nitrogen, 0.7 per cent phosphorus and 3.5 per cent potash. The Indian sea-weeds *Gracilaria, Sargassum* and *Turbinaria* have on dry-weight basis 1.48, 1.02 and 0.96 per cent nitrogen; 0.07, 0.2 and 0.27 per cent phosphorus; and 0.7, 5.9 and 9.1 per cent potash respectively. In 1960, Thivy devised a cottage-industry method of preparing sea-weed compost at the Central Marine Fisheries Research Station, Mandapam Camp, Tamil Nadu. In this method the sea-weed, *Hypnea*, is placed in 15-cm thick layers with one-and-a-half layers of alternating dry-powered cowdung and the whole mound is sealed with clay and smeared with cowdung. The mound is regularly watered to keep the contents moist. The sea-weed compost takes about two months to reach chemical stability.

The field trials conducted with *bhindi* showed that the yield per plant per season treated with *Hypnea* compost was 73 per cent more than in plants treated with cowdung and ash. Similarly, brinjal, tapioca, *Gyamopsis, Dolichos*, gourds, lime, papaya and drumstick also gave good results when manured with sea-weed compost.

CHAPTER X

SOIL AMENDMENTS

THE word soil amendment in its restricted sense denotes any substance which is used to correct the reaction of the soil and make it suitable for plant growth. According to the *U.S.D.A. Yearbook* (1957) material, such as lime, gypsum, saw-dust or synthetic soil conditioner, that is worked out into the soil to make it more productive is called soil amendment. Broadly speaking, a fertilizer is also an amendment, but the term amendment is used commonly for the added materials other than the fertilizers soil conditioners.

The soils in humid regions are generally acidic in reaction and the practice of liming of such soils to correct the acidity and create favourable conditions for plant growth is as old as agriculture itself.

Just like acidity in humid regions alkalinity is the major problem of soils in arid zones. For the reclamation of alkaline soils gypsum is often used. A number of other amendments are also commonly used for correcting the acidity or alkalinity of the soil and making it suitable for crop production.

ACID SOILS AND THEIR AMENDMENTS

The acid soils have pH below 7, generally 4–7. Their acidity increases as the pH decreases. The most important causes of acidity in such soils are stated below.

Causes of acidity. Leaching of bases, like calcium and magnesium, due to heavy rainfall and excessive drainage increases the concentration of H ions in the soil and causes acidity.

Removal of bases by plants exceeding the return of bases in the form of fertilizers and manures also lowers pH of soils.

Continuous application of fertilizers, like ammonium sulphate, produces sufficient acidity to lower the pH value of the soils. For example, in a continuous fertilizer experiment at Shahjehanpur Sugarcane Station, pH and exhangeable calcium of the soil decreased as a result of continuous use of ammonium sulphate; and at Gurdaspur in a soil with an initial pH of 7.5, continuous use of ammonium sulphate lowered the pH to 6.75.

Accumulation of organic matter due to humid conditions and formation of carbon dioxide and other organic acids results in the replacement of bases from the soil complex with H ions and then makes the soil acidic.

Acidic soils. In an acid soil the availability of nutrients, like aluminium, manganese and iron, increases with increase in acidity, thus becoming toxic to plants. The availability of phosphorus also increases, but as the pH falls as low as 4, secondary reactions between aluminium, iron and the phosphates occur and the soluble phosphate again becomes unavailable to plants. This phenomenon is particularly most noticeable in laterite soils.

Inadequate supply of calcium and magnesium in acid soils affects growth of plants. In a critical experiment on a low exchange capacity soil in North Carolina, Calwell and Brady (1945) found a correlation of 0.95 between the exchangeable calcium and ratio of the yield of the control plots to the yield of the limed plots for the group of experiments. They also obtained high yield when gypsum was applied, which did not affect the pH but supplied calcium.

Of the micro-nutrients the availability of molybdenum decreases and that of boron, zinc and manganese increases as the pH falls.

Decomposition of organic matter, mineralization of organic nitrogen and organic phosphorus decreases as the pH of soil falls. Same is the case with nitrogen fixation. Thus, in acid soils plant growth is adversely affected. Most of the crops like lucerne, clovers and other legumes, do not flourish in acid soils. The yield of many other crops, like cotton, wheat and maize, is also adversely affected.

Treatment for acid soils: Liming to reduce acidity of soils is a routine practice all the world over. The materials commonly used for this purpose are oxides, hydroxides, carbonate, silicates of calcium and magnesium, limestone ($CaCO_3$), dolomite limestone $CaMg(CO_3)_2$, basic slag, marl, chalk, hydrated lime and burnt lime. The other materials, which may be used are pressmud of carbonation sugar factories, precipitated lime, a by-product of Sindri Fertilizer Factory, and oyster shells. In soils with low buffering capacity and low cation exchange capacity, application of fertilizers like bone-meal or calcium ammonium nitrate also serves as an amendment for acidity in addition to their utility as sources of nutrients.

Compounds used for correcting acidity

Calcium carbonate or limestone: It is finely-ground limestone. It reacts with the soil and neutralizes acidity.

Hydrated lime, burnt lime and dolomite limestone, which contains $CaMg(CO_3)_2$, also react in the same way as carbonate of lime. The dolomite limestone besides supplying calcium also supplies magnesium. Some of the high calcium limestones also contain significant percentages of magnesium.

The quality of crystalline limestone depends on the degree of fineness and the amount of impurities, such as clay, which they contain. The neutralizing value of commercial limestone usually is 65–70 per cent to a little over 100 per cent. The neutralizing of chemically pure $CaCO_3$ has been arbitrarily fixed as 100, and that of most of the agricultural limes is only 90–98 per cent because of impurities. The comparative neutralizing powers of various liming materials are given below:

Material	*Neutralizing value*
CaO	179
$Ca(OH)_2$	136
$CaMg(CO_3)_2$	109
$CaCO_3$	100
$CaSiO_3$	86

With most liming materials the reaction with H ions usually results in the formation of either H_2O or H_2CO_3. Thus, gypsum which contains $CaSO_4\ 2H_2O$ cannot correct acidity of the soil, as it will result in the formation of sulphuric acid, which is a highly dissociated acid. Therefore, activity of H ions would not be reduced, as it would tend to be readsorbed.

Calcium oxide (burnt lime, quick lime or unslaked lime): It is a white powdery substance, manufactured by roasting limestone ($CaCO_3$), when CO_2 is given off leaving CaO behind. When added to soil and thoroughly mixed it reacts. If mixing is not thorough it absorbs moisture from the soil and forms a sort of protective coating of $CaCO_3$ owing to reaction with CO_2 of the atmosphere. Thus, its reactivity is lowered.

Calcium hydroxide (slaked lime, hydrated lime or builders' lime): It is also a white powdery material, difficult and unpleasant to handle.

Slags: These are by-products of iron industry, and mostly $CaSiO_3$, which act just like $CaCO_3$ as liming material. The most common slags are of three types: (*i*) blast furnace slag, (*ii*) basic slag, and (*iii*) electric furnace slag.

The *blast furnace slag* is the by-product of the pig-iron industry. Its neutralizing value is 75–90 per cent.

The *basic slag* is a by-product of steel industry: Its neutralizing value is 60–70 per cent. It is used as a phosphatic fertilizer rather than as a liming material. Its production in India is increasing, as the steel industry expands, but it is of poor quality as a phosphatic fertilizer because of its low phosphate content; it has tremendous potentialities of use as liming material, particularly in the acid soils of the States where the steel factories are located.

The *electric furnace slag* is the by-product of the phosphorus industry. Being a waste product with a low content of phosphorus (0.9–2.3 per cent P_2O_5), its use is generally restricted to the limited radius of the point of its production. Its neutralizing value varies from 65–80 per cent.

Marl or chalk: This is a loose, friable calcium carbonate, which usually contains varying amounts of clay, organic matter and some magnesium carbonate. Its neutralizing power is 50–90 per cent. As it does not require grinding it can be used in areas where grinding machinery is not available.

By-product liming materials: These include pressmud from sugar industry, dust from marble works, silicate slags, sludges from paper mills, waste from gas works, and precipitated lime from fertilizer factories. Out of these, pressmud and precipitated lime require special mention. In the sugar factories lime is added to the juice and carbon dioxide is passed through it for clarifying; the resultant product is called pressmud. It has the following composition:

Constituents	Deccan Sugar Factory (per cent)	Hamira Sugar Factory (per cent)	Phagwara Factory (Pb.) (per cent)
	Talati (1947)	Minhas (1955)	Chawala (1960)
Organic matter	5.0–5.5	8.69	8.77
Nitrogen (N)	0.8–1.0	..	0.92
Phosphoric acid (P_2O_5)	2.5–3.0	1.25	1.83
Potash (K_2O)	0.80	0.80	0.84
Lime ($CaCO_3$)	68.0	71.23	62.3

Pressmud has been found to be an excellent liming material because of its friable nature, fine particle size, organic matter and nutrient content. It is even preferable to lime. When added on the basis of its calcium content, it is as effective an amendment as lime in the reclamation of acid soils (Table 58).

Wood-ash: Wood-ash generally contains 30–40 per cent lime, 4–6 per cent K_2O, considerable amounts of SiO_2 and small amounts of other minerals. Wood-ash from hard woods contain more calcium than those from soft woods. Freshly burnt wood-ash contains calcium mainly as CaO but on exposure to moisture is converted in the carbonate form. Coal ash has little liming value and benefits ascribed to it are probably the result of improvement in the physical condition of the soil.

TABLE 58. EFFECT OF LIME AND PRESSMUD ON WHEAT IN AN ACID SOIL OF PALAMPUR

Treatment	Yield of wheat (in kg) per 0.45 hectare	
	1958–59	1959–60
Control	265	490
Pressmud	336	632
Lime	304	640
Pressmud—NP (40:40)	..	955
Lime—NP (40:40)	..	898
L.S.D. @ 5 per cent	35.2	104.4

Lime from Sindri Factory: In the manufacture of ammonium sulphate at Sindri by the treatment of ammonia with gypsum and carbon dioxide, calcium carbonate is formed as a by-product. It has the composition given at page 258.

Being a precipitated product it does not require further grinding. Because of the presence of about 1.6 per cent ammonium sulphate its use as liming material is very desirable. It has tremendous potentialities in acid soils of Bihar and other adjoining areas.

Constituents	*Percentage*
Calcium carbonate	80.05
Calcium sulphate	2.35
Ammonium sulphate	2.60
Silica	9.50
Mixed oxides	0.82
Magnesium oxides	2.92

LIME

The effectiveness of lime depends upon a number of factors, the most important of which are discussed below.

Fineness of limestone. The speed with which liming substance reacts with soil depends upon the fineness of the material. CaO, $Ca(OH)_2$ and pressmud, which are powdery by nature, are very effective, whereas in crystalline limestone and slags the effectiveness depends upon the degree of fineness. The finer the material the more effective it is. With fineness the cost also increases due to grinding. The materials requiring minimum grinding and containing sufficient fine particles to affect desired pH change are preferable.

The limestones used in farming contain both fine and coarse materials, for obtaining a fairly good distribution of both the coarse and fine particles. In the U.S.A. most of the State Laws require that 75–100 per cent lime should pass through 8–10 mesh and 20–80 per cent from 8–100-mesh sieves. In Ohio (U.S.A.) the following efficiency ratings for limestones of various degree of fineness have been worked out :

Nature of the material	*Efficiency rating*
Material passing through 60–100-mesh sieve	100
Material passing through 20–60-mesh sieve	60
Material passing through 8–10-mesh sieve	20

For calculating the effectiveness of the limestone the percentage of the particles of various sizes is determined by sieving, and

comparative efficiency is calculated by using the above efficiency ratings. For instance, a lime material containing 40 per cent particles of 60-mesh size, 40 per cent particles of 20–60-mesh size and 20 per cent particles of 9–20-mesh size will have an efficiency rating of 68.

It is only proper to use the lime material which cost least per unit of neutralizing value.

Application method. Since the object of liming is to replace H ions with Ca ions and to neutralize acidity, an intimate contact between the liming material and the soil complex would increase its effectiveness. For most crops, particularly legumes, lime should be applied 3–6 months before the time of sowing of the crop so that lime may react with the soil. This is very important in case of highly acid soils. Generally, it should not be applied later than one month before sowing a crop. The caustic forms of lime, such as slaked lime $Ca(OH)_2$ and quick lime (CaO), though quickly effective should be applied some time before sowing the crop in order to avoid their harming the germinating plants by their caustic nature. Application of lime and its ploughing immediately after harvesting the crop is a sound practice, as it allows some time for the lime to react with the soil.

Frequency: Frequent light applications are preferable in sandy soils, while in case of heavy soils larger application may be made at one time. The finely divided material should be applied in light doses. It reacts rapidly and gets lost quickly but the coarse material because of its slow action has a more lasting effect.

Place in rotation : Generally, best results are obtained if lime is applied with or ahead of the crop. The other important factors determining the effectiveness of lime are the nature of the crop and length of its rotation.

Beneficial effects on the soil. The beneficial effects of lime on the soil are chemical, physical and biological.

Chemicals: When an acid soil (say with a pH of 4.5) is limed to a more suitable pH (say 6.5), the following changes occur:

1. The concentration of H ions decreases because of the hydroxyl ions (OH) increases.
2. The availability of phosphates increases because of the reduction in solubility of A1, Fe and Mn. However, if liming is done beyond pH 7, it is possible that availability of phosphorus may decrease again, because of the forma-

tion of more insoluble compounds of calcium and magnesium.

3. The solubility of aluminium, iron and manganese decreases and their toxicity is removed.
4. The amount of exchangeable Ca and Mg increases and the deficiency of these elements is met with. The striking effect of lime in many acid soils is not due to the increased availability of Ca and Mg, but due to the indirect effects on the availability of other nutrients. However, for certain crops, like legumes, lime is a source of plant nutrients like calcium and magnesium.
5. The effect of lime on the availability of potassium is quite complicated, because this may increase or decrease depending upon a number of other factors. Generally, calcium by replacing potassium from exchange complex should make more potassium available to plants, but it may also happen that by stimulating the growth of soil micro-organisms it may temporarily immobilize potassium. Moreover, the antagonism between K and Ca is also well known. If the soil is overlimed the availability of potassium may decrease.
6. Availability of micro-nutrients, particularly of molybdenum, increases with lime, while that of zinc, manganese and iron will be in the optimum range when pH of the soil is adjusted to 6.5 or 7.0.

Biological effects: Liming affects the microbiological population of the soil and effects nitrification and nitrogen fixation profoundly. Since most of the organisms responsible for the conversion of ammonia to nitrate require large amounts of active calcium, liming of a soil to pH 6.0 or 6.5 is more favourable for the activity of nitrate-forming bacteria and stimulating proper mineralization of organic matter, thus eliminating toxic substances.

Liming also favours symbiotic and non-symbiotic nitrogen fixation. The growth of legumes is encouraged and they fix more nitrogen. The growth of non-symbiotic nitrogen-fixing organisms is also stimulated; this results in more fixation of nitrogen.

Physical condition of the soil: Liming improves the structure of soils. In case of heavy soils of low pH, its application besides affecting the availability of nutrients and creating favourable conditions for growth of beneficial micro-organisms, also results in better structure of the soil and less erosion.

Effect of overliming. If the soil is overlimed or pH raised beyond 7 the lime can be harmful instead of being beneficial. The detrimental effects may be due to one of the following causes:

(*a*) deficiency of available iron, manganese, copper and zinc;
(*b*) reduction in availability of phosphate as more insoluble type of Ca and Mg phosphates are formed;
(*c*) disturbance in uptake and utilization of boron because of the antagonisms between calcium and boron; and
(*d*) reduction in availability of potash.

The sandy soils with low cation exchange capacity are more susceptible to harm than the heavy soils. Similarly, soils with kaolinite type of clay minerals may do more harm than those with 1:2 type of clay minerals. Highly organic soils are less likely to suffer from overliming than the mineral soils.

Lime requirements of soils. The most common index of lime needs of a soil is its pH, but it determines only the active acidity or the hydrolysable H ion concentration in the soil. The soil being a buffered medium has considerable amount of reserve or potential acidity or H ions, which will dissociate as soon as the active H ions are neutralized by liming. Thus, a method which takes into consideration both the active and potential acidity of the soil is more useful than any other. Since the potential acidity of a soil depends upon its cation exchange capacity and buffering, these factors also deserve consideration. As the pH value alone is not a criterion of the amount of lime to be added to a soil, the indiscriminate use of pH test kits by persons unfamiliar with the principles of soil chemistry is dangerous. However, the pH values of soils, which have been properly classified and their lime requirement determined accurately in the laboratory, can be used as an index of its lime requirements provided the organic matter content and texture of the soil are also taken into consideration.

The pH of a soil water suspension is usually determined by a pH-meter using glass electrode. Certain dyes or indicator solutions can also be used for this purpose.

Other methods make use of the exchange acidity. The soil sample is allowed to react with buffer solution, specially formulated to react with soil acidity. The amount of acid released from this buffer solution can be measured and expressed as an amount of lime needed. This method, proposed by C. M. Woodruff of the University of Missouri, is used in many soil-testing laboratories of the U.S.A.

Another method, quite accurate and reliable, is based on titration curves of the soil with $Ca(OH)_2$. Here 10 g of soil sample are taken in a number of beakers and to every beaker a given amount of $Ca(OH)_2$ or HCl solution is added. Water is also added to equalize the volume of liquid in all beakers. The samples are allowed to come to equilibrium. The pH determinations are made and the amount of $Ca(OH)_2$ or HCl added, and the pH obtained are plotted on a graph. From the curve thus obtained the lime requirement of the soil for raising its pH up to 6.5 is calculated.

In Puri's Method (1949) the soil is treated with excess of calcium carbonate and the total amount of Ca extractable with potassium oxalate, carbonate, acetate solution is determined before and after treatment with $CaCO_3$. The difference in the exchangeable calcium originally present and after shaking with $CaCO_3$ is a measure of the lime requirement of the soil.

Kanwar and Bhumbla (1959) suggested a ready reckoner for determining the lime requirements of acid soils of the Punjab.

Allaway (1957) suggested the following approximate rates of ground limestone to correct acidity of the surface 17.5 cm of the soil in the soil in the U.S.A.:

Soil region and texture type	*Limestone requirements (kg/ha)*		
Soils of warm, temperate and tropical regions	From pH 3.5–4.5	From pH 4.5–5.5	From pH 5.5–6.5
Sand and loamy sand ..	753	753	1,004
Sandy loam	..	1,255	1,757
Loam ..	..	2,088	2,510
Silt loam ..	..	3,012	3,514
Clay loam ..	..	3,765	5,020
Muck ..	6,270	8,283	9,538

The rates suggested for soils of cool temperate region are higher.

Effect of lime on the yield of crops. Liming has more indirect benefits than direct. Besides supplying calcium and magnesium and increasing the pH, it also increases the availability of many nutrients, and thus increases crop yields indirectly. The following extracts indicate the response to liming in acid soils of different parts of India.*

Assam: The old alluvial soils with high acidity are generally unsuitable for the *rabi* crops, such as mustard and pulses. An application of 18 q of lime per hectare corrects soil acidity and results in high yield of *rabi* crops and potatoes.

Tamil Nadu: Liming seems to be essential in West Coast area and in the Nilgiris tract for pepper, potatoes and *sanai*.

Bihar: Liming has given very encouraging results in maize, wheat, gram, soybean and groundnut in acid soils of Ranchi (Mandal, 1960, personal communication) as shown below:

AVERAGE YIELD (KG|0.45 HECTARE; EXPTS. CARRIED FOR FOUR YEARS)

Treatment	*Maize*	*Wheat*	*Gram*	*Soybean*	*Groundnut*
Control ..	270	253	72	64	250
Lime ..	455	318	170	345	557
NPK ..	570	416	174	136	295
NPK lime ..	825	580	408	547	636

It is apparent that liming not only increased the yield in non-fertilizer treatments but also increased the efficiency of fertilizers particularly in legumes: gram, soybean, groundnut, etc. Beneficial effect of liming has also been observed in *jowar*, *mung*, *arhar*, *mahua*, cotton, peas, barley, *masur*, linseed and mustard. However, liming did not produce any appreciable effect on paddy (Mandal *et al.*, 1955).

Orissa: Continuous application of lime for ten years at the Rice Research Institute, Cuttack (Anon., 1959), did not affect the yield of paddy and soil reaction in any manner, nor was there any difference in the exchangeable bases in the limed and unlimed soil.

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*Sufficient data about the effect of liming on Indian soils are not available.

Punjab : Effect of liming and fertilizer application on the yield of various crops in an acid soil of Palampur is tabulated below:

Treatment	Wheat (3 years)	Maize (3 years)	Potatoes (3 years)	Paddy (3 years)
	Yield in kg per 0.45 hectare			
No lime				
Control ..	290	894	3,510	744
N	422	1,259	6,256	972
NP	717	1,556	4,875	1,209
NK	506	1,338	6,802	1,050
PK	543	1,304	5,634	965
NPK	820	1,685	9,752	1,294
With lime				
Control ..	336	946	3,697	807
N	463	1,318	6,182	1,029
NP	754	1,631	8,835	1,293
NK	544	1,366	6,948	1,123
PK	618	1,340	5,863	1,052
NPK	862	1,776	10,026	1,392
Mean yield with no lime	549.7	1,339.3	6,138.2	1,039
Mean yield with lime	596.0	1,396.0	6,925.2	1,116.0
Doses (kg per 0.45 ha)				
N	40	50	100	25
P_2O_5	40	50	100	50
K_2O	40	100	200	50

The experiments conducted during 1958–60 under the Hill Soil Scheme on Cultivators' Fields in Palampur area (Kangra) revealed that unfertilized soil showed quite a high response to liming in wheat, maize and potato, but in the presence of fertilizers the margin of differences narrowed down. On the whole there were higher yields in limed plots than in the unlimed ones. The effect of fertilizers was very marked, particularly in combination with phosphate. This shows that this soil is more responsive to phosphate than to nitrogen. In paddy there is perhaps no significant effect of liming, though it may increase the yield over no liming treatment. Liming in soils of Kulu (pH above 6.0) affects most of the crops insignificantly.

West Bengal: In Chinsurah, Suri and Behrampur State Agricultural farms, liming did not appreciably increase the yield of paddy though the treatment with ammonium sulphate was highly beneficial (Mukerjee, 1960, personal communication Table 59).

Similar results have been reported from Burdwan and Cooch Behar Experimental Stations.

Mysore: Liming at the rate of 2,486–4,972 kg|ha produced a marked increase in the yield of paddy at Shimoga and Ponnampet (Anon., 1959), the increase being 460–920 kg|ha for one ton of lime at Ponnampet and 15,413 kg|ha for 2,030 kg of lime at Shimoga.

AMENDMENTS FOR ALKALI SOILS

The saline-alkali soils suffer from high salt concentration and high pH. The predominant cation in the exchange complex is sodium and likewise the soluble salts are mostly of sodium. The reclamation of such soils aims at: (*a*) the replacement of exchangeable Na with Ca, (*b*) removal of excess of soluble salts, and (*c*) restoration of the fertility of the soil.

The chemical soil amendments which are commonly used for reclamation may be divided into:

(i) soluble calcium salts, calcium chloride and gypsum.
(ii) acid-forming amendments, viz., sulphuric acid, aluminium sulphate, iron sulphate and molasses; and
(iii) calcium salts of low solubility, pressmud of carbonation or sulphitation sugar factories and lime of fertilizer factories.

Present researches in India have shown that use can be made of acidifying fertilizers like ammonium sulphate, ammonium chloride (Kanwar and Bhumbla, 1959) and hydrogen-saturated coal (Puri, 1960, personal communication) in the reclamation of such soils.

Gypsum: Gypsum is the most common amendment used in reclamation of alkali soils. It is a white mineral, occurring extensively in natural deposits. Usually, it is ground before applying to the soil. It influences the physical conditions of the soils. It reacts with the alkali soils, replacing sodium with calcium ions, which have favourable effect on soil structure, permeability to air and water, and ultimately on plant growth.

TABLE 59. MEAN YIELD OF PADDY (KG PER 0.45 HECTARE)

Treatments	(N in kg|0.45 ha)				Average for lime
	0	20	40		
Chinsurah Farm (1946–59)					
0 cwt lime|hectare ..	836	982	1,071		962.94
4 cwt lime|hectare ..	855	982	1,053		966.67
8 cwt lime|hectare ..	907	997	1,090		996.54
Mean ..	866	987	1,071		974.72
Suri Farm (1948-58)	0	30	60	90	Average for lime
0 cwt lime|hectare ..	747	1,093	1,176	1,028	1,011.11
4 cwt lime|hectare ..	914	1,047	982	1,104	1,011.48
8 cwt lime|hectare ..	925	1,023	1,072	1,026	1,011.11
Mean ..	862	1,054	1,076	1,053	1,011.23
Behrampur Farm (1949-59)	0	30	60	90	Average for lime
0 cwt lime|hectare ..	272	488	567	516	460.94
4 cwt lime|hectare ..	222	485	586	569	465.79
8 cwt lime|hectare ..	229	458	520	580	446.76
Mean ..	241	477	558	555	457.83

Any sodium carbonate in the soil reacts with gypsum and is changed into calcium carbonate if sufficient water is applied to leach down the sodium sulphate formed as a by-product. In soils having soluble salts in the form of sulphates it may be necessary to leach out the greater part of the sulphate; otherwise the solubility of gypsum will be too low to effect satisfactory replacement of exchangeable sodium with calcium.

The rate of reaction of gypsum is limited by its solubility in water which is about 0.25 per cent. Under field conditions, 37 to 49 cu-m of water is required to dissolve four to five tonnes of high-grade agricultural gypsum.

Since gypsum is only moderately soluble in water a considerable quantity of irrigation water is required for its full effect. In many alkali soils there is quite a high percentage of exchangeable sodium in the subsoil. In order to replace exchangeable sodium from deep layer, gypsum or other substances applied to the surface must be leached down. Moreover, the effectiveness of the replacement of sodium with calcium will also depend on the nature and amount of soluble salts in the deeper layers of the soil.

The selection of an amendment is governed by considerations of cost and the time required for its reaction in the soil. Gypsum and sulphur are more often used for the reclamation of alkali soils than sulphuric acid, aluminium or iron sulphates or calcium chloride. In India, due to shortage of sulphur and acute demand for it in industry, the only suitable and cheap material available for reclamation purposes is gypsum, rich deposits of which are found in Bikaner and Jodhpur (Rajasthan). It also occurs in sufficient quantities in Tamil Nadu, Kutch and Himachal Pradesh. Good grade of gypsum is used for the manufacture of ammonium sulphate at Sindri. The lower grade, which contains 60–70 per cent $CaSO_4$, is used as an agricultural amendment. The Indian Railways allow a concession in freight of gypsum meant for reclamation purposes.

WORK DONE ON GYPSUM IN INDIA: In the Punjab, Singh and Nijhawan (1943) found that the deficiency of exchangeable calcium in alkali soils can be made good by the application of gypsum. In U.P., Yadav and Agarwal (1959) observed that gypsum invariably brought about better removal of all the ions than the treatment without gypsum. Its action was attributed to the improvement in the hydraulic conductivity of the soil. Islur (1941) concluded that in the reclamation of alkali soils gypsum is the only popular chemical throughout the world. The maximum dose of gypsum used in

Treatment	YIELD (kg/0.45 hectare)					Changes in pH	
	1956	1957	1958	1959	Mean yield per 0.45 hectare	1956	1959
Control ..	71.6	320.3	329.5	958.4	435.7	9.70	8.83
Pressmud (2–2–4–0 tons*)	68.9	280.4	698.2	1,224.2	567.9	9.50	8.92
Gypsum (2–2–4–0 tons*) ..	38.5	310.3	535.5	1,029.9	478.5	9.00	8.90
Fertilizer (N50 + P25, every year) ..	111.7	689.0	906.0	1,168.1	718.7	9.60	8.75
Fertilizers + pressmud (B-D)	77.7	765.6	981.1	1,176.1	750.1	9.60	8.97
Fertilizers + gypsum (C-D)	38.5	712.6	969.3	1,125.5	711.7	9.82	8.52
F.Y.M. 15 tons* every year	120.0	795.5	916.3	1,326.1	791.9	9.42	8.76

*One ton = 1016.05 kg

Deccan is 7,530 kg|ha. Talate (1941, 1947), in Bombay, observed that gypsum and sulphur in combination with farmyard manure have proved the best amendments for alkali soils, and that gypsum, when applied at the rate of 4,972 to 7,530 kg|ha, significantly increased yield of crops in alkali soils of Deccan.

Application of gypsum as a soil amendment is very essential for soils with high pH in the Punjab, particularly where water-table is high.

Effects of gypsum and some soil amendments on the yield of paddy and changes in soil pH of saline-alkali soil at Kamma are tabulated on page 268.

It is apparent that pressmud and gypsum have both effectively increased the yield of paddy and also lowered the pH. Fertilizers either alone or in combination with the amendments produced best effects. Though farmyard manure gave good results, its application is not as economical as that of fertilizers alone.

In another experiment, conducted on a saline-alkali soil of Kamma, gypsum at the rate of 13.45 tonnes|ha was added to one-half of each plot in 1958–59 and its effects on the yield of various crops were studied. During 1959–60 only the residual effect of gypsum treatment was studied. A marked direct and residual effect of gypsum was observed on all the crops, though wheat, barely, cotton and Sudan grass showed more pronounced effect, as shown in Table 60.

Effect of degree of saturation with gypsum has been studied on a soil with pH 9.5–10,0 at Kamma. The gypsum was applied only during the first year before transplanting paddy. Its residual effect was studied. The effect of degree of saturation with gypsum on the yield (kg|0.45 hectare) of paddy and barely grains at Kamma is given in Table 61.

It was observed that yield increased with the degree of saturation with gypsum. A similar experiment was conducted in pots on Kamma soil, which was treated with Na_2CO_3 so as to make it more alkaline. The soil was treated with gypsum, pressmud, gypsum + NPK and pressmud + NPK at different levels, i.e., 0, 10, 15, 30, 50, 70 and 100 per cent of the gypsum requirements of the soil. Wheat was sown eight months after the application of gypsum or pressmud. After wheat residual effect was studied on paddy.

The best effect was produced by the addition of gypsum or pressmud at 30 per cent of the gypsum requirement of the soil and addition of NPK further enhanced this effect many times.

TABLE 60. DIRECT AND RESIDUAL EFFECT OF GYPSUM ON DIFFERENT CROPS (kg|0.45 hectare)

Crop	1958-59		1959-60	
	Without gypsum	With gypsum (direct effect)	Without gypsum	With gypsum (residual effect)
Paddy	739.3	883.3	955.9	853.1
Paddy after *dhaincha*	470.7	458.6	798.6	617.1
Cotton	2.4	15.7	110.1	198.4
Sudan grass ..	1,316.6	1,972.3	3,509.0	6,473.5
Wheat	463.4	500.9	255.3	452.5
Barley	412.6	785.3	220.2	396.8
Sugar-beet ..	6,088.7	7,989.6	4,913.7	5,017.2
Taramira	101.6	211.7	41.1	93.2
Senji (grain) ..	428.3	582.0	222.6	556.6

TABLE 61. EFFECT OF DEGREE OF SATURATION WITH GYPSUM ON THE YIELD (kg|0.45 hectare) OF PADDY AND BARLEY

Treatment	Paddy		Barley	
	1958–59	1959–60	1958–59	1959–60
Control				
50 % G.R. ..	125	512	102	130
75 % G.R. ..	280	612	36	136
75 % G.R. ..	414	772	317	197
85 % G.R. ..	263	656	288	184
100 % G.R. ..	347	732	318	181

It was seen that when gypsum was applied at various levels in the soil there was a fall in pH; the maximum reduction was effected by the highest level of gypsum. But it may not be economical to use such a high dose. The lower dose, applied at 30 per cent of the gypsum requirement, seems to be the most economical.

In field experiments on saline-alkali soils at Basi Farm in Rajasthan, Mehta observed that annual application of gypsum at 10 tonnes per hectare and 25 tonnes of FYM in May and June along with 9 kg nitrogen and 13.6 kg P_2O_5 per 0.45 ha produced, on an average in three years, 220 kg of wheat grain as against 653 kg in control plots.

Agarwal (1957) observed that application of gypsum at the rate of 7,458–12,430 kg|ha increased the yield of paddy in an alkali soil in U.P. by 1.97 per cent over the control. Gypsum when applied with *dhaincha* (green manuring) gave 275 per cent over the control.

Pressmud: Its total quantity available in India has not been estimated, but because of the large number of sugar factories in the country it must be available in fairly large quantities. Its effectiveness in saline-alkali soils seems to be due to the small size of $CaCO_3$ particles which can come in direct and intimate contact with the soil, react with the exchange complex and replace sodium with calcium. Pressmud compares favourably with gypsum, though the speed of reaction is slow. In an experiment 20 g of soil were mixed with 0.16 g of gypsum or pressmud each separately and 50 and 100 ml of water was used for the suspension. The suspensions in duplicate were incubated for 1, 10, 15, 30 and 60 days and the changes in pH and percentage of Ca retained in the soil from gypsum and pressmud were studied. Gypsum was far more reactive than pressmud but in the presence of a growing crop the pressmud became equally effective.

Sulphur: Elemental sulphur, where locally available at a low cost, may be used successfully in the reclamation of saline-alkali soils containing lime ($CaCO_3$). In the laboratory when incorporated in the soil in the form of fine powder, it is oxidised to sulphuric acid within two to three weeks (McGeorge and Green, 1935). Theoretically speaking one ton of sulphur is as effective as 4,460 kg of gypsum. Therefore, if the cost permits it should be used for reclamation of alkali soils containing reserves of calcium carbonate. However, its high cost does not permit its extensive use in India.

Sulphuric Acid: When applied directly to the soil containing $CaCO_3$ through irrigation water sulphuric acid reacts immediately with the soil and produces quick results. But because of its cost and difficulties in handling it is seldom used. Where high alkalinity and presence of hard pan of $CaCO_3$ near the surface prevents growing anything, commercial sulphuric acid may be used. It will react with $CaCO_3$ and change it to calcium sulphate and break the hard pan. The $CaSO_4$ thus formed will also react with the soil complex and replace sodium with calcium ions.

Aluminium Sulphate and Iron Sulphate: These salts are acid formers, hydrolyse in water and form sulphuric acid which reacts with the soil. Because of the high cost their use as soil amendments has not become popular.

SOIL AMENDMENTS IN SALINE-ALKALI SOILS

Since selection of an amendment for the reclamation of saline-alkali soils depends upon the nature of the soil, its cheapness and availability, its effectiveness can be increased if the material is thoroughly incorporated in the soil. Amendments, such as gypsum, pressmud and sulphur, are broadcast as powders on the field, and later ploughed in. In some cases leaching of the salts becomes essential before the application so that the soluble calcium in the amendment may react more and more with the exchange complex of the soil and replace sodium. Leaching is more essential in soils with predominant soluble sulphates. Because of the common ion effect the solubility of gypsum will decrease in such soils. However, the advantage gained through increased efficiency in exchangeable sodium replacement by leaching prior to the application of amendments may be more than offset by the decrease in soil permeability that usually accompanies leaching. Therefore, whether an amendment should be applied before or after the removal of soluble salts, will depend upon the permeability relationships. Since permeability is very low in saline-alkali soils leaching is done immediately after the addition of an amendment, except in certain cases where the predominant salts are sulphates, or sulphur is used as an amendment. Leaching dissolves and carries the sodium amendment downwards; it also removes the soluble salts that form as a result of cation exchange. Soils receiving sulphur ordinarily should not be leached until sufficient time has been allowed for most of the sulphur to be oxidised to form gypsum. The soil should

be kept moist as moisture is essential to the process of microbial oxidation. It is sometimes convenient to apply water-soluble amendments in the irrigation water. A simple method of applying gypsum in irrigation water consists of placing a bag of the amendment with the side slit open in the irrigation ditch preferably at a place where the water has sufficient turbulence.

GYPSUM REQUIREMENTS OF SOILS

In the reclamation of a soil it is not necessary to replace all the exchangeable sodium with calcium, rather, it is desirable to reduce the percentage of sodium to such a level that the soil structure is improved and plants are able to get a foothold. Wayynne and associates emphasized that instead of basing the calculation on the complete removal of sodium, it is often desirable to reduce the sodium to 10 per cent of the exchange capacity to permit satisfactory crop growth. The natural processes, such as root activity, irrigation and leaching, can complete the removal of sodium, but most field situations do not result in quantitative exchange of sodium with calcium from the amendment. Some tests indicate that an excess of about 25 per cent should be allowed over and above the calculated amount of amendment required for lowering the exchangeable sodium to the desired level. In the U.S.A. when the exchangeable sodium percentage of soil exceeds 25, 90 per cent or more of the calcium supplied by the amendment replaces exchangeable sodium as the soil is leached. The percentage of added calcium, that replaces exchangeable sodium, does not become less than 50 until the exchangeable sodium percentage becomes less than 10.

Of the various proposed rapid methods for the determination of gypsum requirements of the alkali soils those of Schoonover (1952), Puri (1949) and Shewarbi (1954) need special mention. In Schoonover's Method a representative soil sample is shaken with a saturated solution of gypsum, and the change in the concentration of calcium represents the gypsum requirement of the soil. One milliequivalent of gypsum per 100 g of soil corresponds to 1,747 kg of gypsum per cubic-metre of soil.

Puri (1958–59) observed a serious lack of agreement in the method referred to above, and stated that a pot-culture method would be better than those for determining the gypsum requirement of a soil. A comparison of those methods was also made in the Punjab on representative samples of saline-alkali soils taken from

Karnal, Amritsar, Hissar, Rohtak, Gurgaon, Gurdaspur and Ferozepur. The values of gypsum requirements by Shewarbi's methods were very high, but there were no significant differences between Puri's Methods and those of Schoonover. From the practical point of view it is not necessary to use such high amounts of gypsum, as indicated by these methods. The field and pot experiments conducted in the Punjab show that application of gypsum at 30 per cent of gypsum requirement based on Schoonover's Method is the most economical and the optimum dose of amendment. For most of the saline-alkali soils of the State the most economical dose of gypsum seems to be 7,530 kg of gypsum per hectare.

It needs hardly be over-emphasized that the application of an amendment is not a substitute for good soil and water management practices. It may be largely ineffective unless the soil is periodically leached and unless the ground water remains at a sufficient depth to present appreciable water and salt movement. If the irrigation water contains a high proportion of sodium and continually adds absorbed sodium to the soil, periodic application of amendments will be needed.

CHAPTER XI

MANURING OF CROPS

Manuring of Horticultural Crops

In considering manurial problems of fruits, attention should be drawn to the special requirements of the different fruit plants for mineral nutrients, other than nitrogen, phosphorus and potassium, and the special relationship that exists between manurial requirements on the one hand and cultural systems and other practices, such as pruning, on the other. The reaction of elements in the soil in relation to tree performance is also very important. Iron and manganese deficiency has been reported to be common in soils which contain much lime or are alkaline, boron to be more valuable in acid soils than in alkaline soils and zinc deficiency to be increased by phosphate concentrations. In slightly alkaline soils, zinc is precipitated and is held out of the soil solution, becoming useless to the plants. Ample organic matter in the soil may change the insoluble phosphate to a form available to the plants and may also react similarly with iron.

In general, vegetables which require intensive cultivation need larger amount of mineral nutrients as compared to the agronomical crops. Cauliflower, cabbage and kno-kho are gross feeders and would greatly benefit from frequent application of nitrogenous fertilizers. Onion, when fed on nitrogen, yields large-sized bulbs, but of soft texture which would not keep well in storage. Pea responds well to a small amount of phosphorus.

Application of manures and fertilizers

Fruits: Cattle manures and stubble of green manures should be ploughed in and incorporated well in the soil, and this must be immediately followed by irrigation. In order to decompose this organic matter more of irrigation and tillage operation may be necessary. If other manures and fertilizers are to be applied, they should be evenly broadcast and mixed well with the soil by irrigation and light surface working of the soil.

At the time of planting only well-rotted manure should be applied in the pits as otherwise it may cause injury to the roots of the plant. Adequate manuring should be given when the tree is well established. In case of poor soils, manuring should be done five to six weeks before planting. It is better to apply manures once a year when the growth is least active or before the blossoming season or before the main growing season of the year sets in. In case of sandy or open soils, where leaching off of the food material is of common occurence, manures should be applied twice a year. Manures and fertilizers should be applied in the basin around the tree, where the feeding roots are largely concentrated. But when the trees are fully grown application should be from trunk to trunk, leaving a small space of 30 or 61 cm around the trunk unmanured.

Vegetables: The proper time to apply manure depends on the kind of manure, stage of its decomposition, crops to be grown and rotations to be followed. When cow-dung manure is used it should be ploughed under as far in advance of planting as convenient. When vegetables are grown in rotation with general farm crops, it is desirable to apply the manure to the vegetable crop or to the crop preceding. Fertilizers for vegetable crops are applied before or at the time of planting. Under most conditions it is best to apply the fertilizer a few days prior to planting. Experiments have shown as good or better results from a single application as from two or more when the same quantity of material is used. Moreover, the cost of two applications is more than that of one.

Usually the manure is broadcast before sowing. Well-rotted manure may be applied to ploughed land and mixed with the surface by harrowing. Manure is sometimes applied in the furrows as in melons and other cucurbits. This is advantageous where the quantity of manure is limited, as it results in greater concentrations in the region of the first formed roots. When the temperature is slightly lower as in February and March in northern India, this method gives better results, as it produces heat in the soil due to fermentation of the fresh manure, and this heat hastens the germination and growth of the cucurbits.

FRUITS

Mango. The fertilizer needs of mango are different at various stages of its growth. Before the sapling is planted in its permanent place the pits should be filled with a mixture of 45.3 kg of well-rotted farmyard manure, 2.2 kg of bone-meal and 4.5 kg of wood-ash (with some top-soil). Allan (1935) suggested that the soil which is to fill the lower 60 cm of the pit be mixed with 13.6–18.1 kg of manure, while to the upper 30 cm 4.5 kg of manure, 0.9–1.3 kg of bone-meal and 0.9 kg *neem*-cake should be added. Naik (1949) recommended a dose of 4.5–5.4 kg of well-rotted farmyard manure per pit. In western India, Cheema *et al.* (1954) advocated a mixture consisting of 11.3 kg of farmyard manure, 0.67 kg bone-meal and 1.12 kg of wood-ash. Gandhi (1955) reported that in the dry zone of North India, subject to fear of white ants during summer, farmyard manure in the manure mixture should be replaced with 2.2 kg of *neem*- or *mahua*-cake.

For most parts of India, Gandhi (1955) recommended an annual general surface manuring of the orchard with farmyard manure at the rate of 21 cartloads per hectare at the commencement of the monsoon. Besides, every individual tree of 10–20 years' age should be manured with a mixture of 45.3 kg of farmyard manure, 6.8 kg of bonemeal and 13.6 kg of wood-ash. Trees bigger in size and older in age need proportionately larger amounts. Naik (1949) suggested that in South India, during the first three to four years of orchard life, two to five baskets of well-rotted cattle manure or 0.9 kg of groundnut-cake with or without 0.9 kg of bone-meal should be applied. For western India an application of 9.0 kg of cattle manure per tree, when one-year-old, increased by 4.5 kg per tree annually until the dose reaches 45.3 kg per tree, has been recommended. To these bone-meal is also added at the rate of 4.5 kg per tree when one-year-old, and increased by 0.45 kg per annum up to 6.8 kg per tree. Beside this, wood-ash at the rate of 4.5 kg per tree should be applied and this should be increased by 0.9 kg per tree per annum up to 13.6 kg per tree. The recommendations by Roy *et al.* (1951), as a result of observations at Sabour, are that a tree of ten years or more should get 0.69 kg N, 0.16 kg P_2O_5 and 0.67 kg K_2O in the form of 90.7 kg of farmyard manure, 1.8 kg of castor-cake, 4.5 kg of bone-meal, 0.9 kg of ammonium sulphate and 13.6 kg of wood-ash in the 'off' year.

Gandhi (1951) recommended that the trees which are found turning yellow and declining in yield should receive ammonium sulphate at the rate of 2.2 kg (for 6- to 10-year-old trees) and 4.5 kg (for 10- to 20-year-old trees).

Manurial trials conducted at Sabour have shown that nitrogen in the form of ammonium sulphate is most effective in increasing flowering. NPK gave better results than nitrogen alone or P and K either single or in combination.

Time of application: Roy *et al.* (1951), at Sabour, recommended that the dose should be split up in two parts—one containing ammonium sulphate and half the potash for June application, and the other consisting of farmyard manure and phosphate along with the remaining quantity of potash for manuring in October. In the 'on' year the dose of ammonium sulphate should be doubled and the extra dose (equivalent to 0.7 kg N) should be applied a fortnight after the June application, immediately after harvest. However, no specific time is mentioned for applying castor cake. Perhaps it is to be given along with the farmyard manure and P_2O_5 in October. The beginning of monsoon is the best time for manuring young trees. In Uttar Pradesh application of 12 cart-loads of farmyard manure per 0.45 hectare or 37.3 kg per well-grown tree just after picking the fruit in the 'off' year is recommended. Afterwards fertilization with 2.2 kg of ammonium sulphate and 0.9 kg of superphosphate should be done at the beginning of January or about seven weeks before new growth and flowers are expected. In order to discourage vegetative growth after harvesting in the 'on' year no manure is recommended. During the month before the new flushes and inflorescences are expected, fertilization should be affected at the rate of 1.8 kg of superphosphate, 0.9 kg of potassium sulphate, 2.2 kg of bone-meal and 4.5 kg of wood-ash.

Method of application: The general dose of farmyard manure should be spread evenly on the ploughed surface and incorporated by harrowing. The manure mixture should be applied in shallow, circular trenches around each plant. These trenches should be 2 to 91 cm wide and 30 cm deep within the drip of the branches.

Salts of micro-nutrients may be given in the form of sprays. It is better to mix these with two or three regular fungicidal sprays.

Tripathi (1961) reported that urea is absorbed by old and young leaves of mango in measurable quantities and the absorption was higher by the young leaves.

Citrus. Different varieties have different requirements and there is considerable variation in the needs of different soils. The dosage of any manure or fertilizer also varies greatly with the same tree depending on its age, health and bearing capacity.. It is because of these factors that there is a great divergence in manurial practices in the citrus orchards located within the same district.

Gandhi (1956) recommended that a one-year-old tree should be given a mixture of 9.0 kg of farmyard manure and 0.22 kg of castor-cake. From the second year onwards, the above quantities should be increased by 4.5 kg and 0.22 kg respectively, every year up to the end of the sixth year.

At Kodur (Andhra Pradesh) good results have been obtained by applying 68–90.7 kg of manure of compost, 3.1–3.6 kg of groundnut-cake and 3.1–3.6 kg of ammonium sulphate. Half of this quantity is to be applied in the months of May-June and the remaining half in December–January.

Nutritional deficiency, which is one of the major causes of decline of *santra* trees in the Nagpur region, can be overcome by adding adequate doses of nitrogenous fertilizers and supplementing the meagre dose of basic manure. For obtaining quick results foliar application of nitrogen in the form of 2–3 per cent urea spray has been found very effective.

The results of the manurial trials in the alluvial soils of the Punjab and Uttar Pradesh have shown that a mixture of 27.2 kg of farmyard manure and 1.8 kg of ammonium sulphate per tree gives good results. In Uttar Pradesh, 9.0 kg of farmyard manure is recommended at the end of the first year and then 3.5 kg of farmyard manure, 0.22 kg of ammonium sulphate, 0.45 kg of wood-ash, 0.22 kg of superphosphate or bone-meal every year for the next five years. Afterwards for four successive years, 0.3 kg of bone-meal and 0.67 kg of wood-ash should be applied in addition to the above-stated mixture. At the end of the tenth year, and subsequently, each tree should receive 40.8–45.3 kg of farmyard manure, 2.2 kg of ammonium sulphate. 2.7 kg of bone-meal or superphosphate and 3.6–4.5 kg of wood ash.

In Madhya Pradesh the formula recommended for orange is superphosphate 13.6 kg, potassium sulphate 7.2 kg, cake 19.9 kg and ammonium sulphate 4.5 kg.

The above mixture should be applied as indicated below:

Age of trees (years)	*Amount of mixture (kg)*
1 to 2	1.3
2 to 3	2.0
3 to 4	2.4
4 to 5	2.7–3.6
5 to 6	4.0–4.5

Thereafter, bearing trees should receive 18.1 kg of superphosphate, 9.0 kg of potassium sulphate, 13.6 kg of cake and 4.5 kg of ammonium sulphate. This mixture should be applied at the rate of 4.5 in the sixth year, 5.4 kg in the seventh year, 6.3 kg in the eighth year, 7.2 kg in the ninth year, 8.1 kg in the tenth year and 9.0 kg in the 11th year. Afterwards, the dose of 9.0 kg per tree is kept constant.

From manurial trials in Assam, the doses of NPK from the first to the 14th year have been suggested as in Table 62.

In south India, application of a mixture, containing one part of ammonium sulphate, two parts of muriate of potash and four parts of superphosphate at the rate of 0.2 kg for young trees, 0.45 kg per plant when 12 to 18-month-old, 0.9 kg per plant when four year-old, and 1.3 kg when seven- to eight-year-old, is recommended. In addition, a leguminous crop like sannhemp, cowpea, horse-gram and *dhaincha*, may be grown in between the trees. Another recommendation is that 9.0 kg of well-rotted farmyard manure is applied to one-year-old tree along with 1.3 kg of wood-ash, 0.45 kg of bone-meal and 0.9 kg of some kind of oilcake. This should be increased gradually till the oilcake and bone-meal are applied to full-grown trees at the rate of 2.2 kg each per tree, farmyard manure at 45.3–54.3 kg and wood-ash at 4.5–5.4 kg per tree.

For trees seven-year-old and above, a mixture of 36.2 kg of farmyard manure, 4.5 kg of castor-cake and 0.9 kg of superphosphate is recommended for the medium black soils of Maharashtra and Gujarat and 4.5 kg of wood-ash for the red laterite soils of South India.

The earlier-mentioned doses can be successfully applied to mandarins. However, for sweet lime, a mixture of 9.0 kg of farmyard manure, 0.45 kg bone-meal and 0.9 kg of some kind of oilcake is to be given for one-year-old tree. From the second year onwards the dose should be increased by equal amounts every year up to the age of seven years. A full-grown tree of sweet lime and *kagzi* lime ranging from 8–20 years may be given 36.2 kg of farmyard manure, 4.5 kg of castor–cake or ground–cake and 0.9 kg of superphosphate.

Time and method of application: In northern India manuring is done in winter (December–January) followed by the application of a dose of ammonium sulphate in April–May after fruit set. In other parts of the country manuring is done at the beginning of the monsoon. Sometimes, in South India, two applications are given—one between June and August and another between December and January. *Kagzi* lime in western India is manured during December and January before the spring flowering.

TABLE 62. DOSES OF NPK PER TREE FROM THE 1ST TO THE 14TH YEAR OF AGE

Age of tree (Years)	Amount of N (kg)	Amount of P_2O_5 (kg)	Amount of K_2O (kg)	Total (kg)
1	0.22	0.16	0.07	0.45
2	0.45	0.31	0.14	0.90
3	1.36	0.45	0.24	1.36
4	0.99	0.63	0.28	1.81
5	1.13	0.73	0.38	2.26
6	1.18	1.02	0.74	2.94
7	1.47	1.25	0.90	3.62
8	1.72	1.51	1.07	4.30
9	2.0	1.72	1.26	4.98
10	2.26	1.98	1.42	5.66
11	2.53	2.26	1.58	6.37
12	2.90	2.53	1.81	7.25
13	3.26	2.86	2.04	8.16
14	3.63	3.18	2.26	9.07

In most parts of India it is a common practice to apply manure in a heap immediately round the trunk, but during recent years some improvement has been effected. It is applied by hand in a ring or basin at a distance of 61 to 91 cm from the tree trunk. By this method maximum benefit is obtained because the manure is applied where the feeding roots are found in abundance. The manures or fertilizers should be spread evenly and incorporated properly in the soil by means of a spade to a depth of 3–10 cm so as to avoid injury to the roots.

Banana. The banana is a gross feeder and plenty of organic manure is necessary for its good growth. At the Central Banana

Research Station, Aduthurai, best results were achieved with 22.6 kg of cattle manure or 1.3 kg of groundnut cake applied as a mixture with 0.56 kg of ammonium sulphate per plant in two doses; half the quantity applied about two to three months after planting and the other half about five months after planting. This is in addition to one basket of cattle manure or compost applied to pits prior to planting where soils are deficient in potash. In addition to the above 11.3 kg of ash per plant should also be applied.

Naik (1949) recommended a mixture of potassium sulphate 76.2 kg, groundnut cake 254 kg and superphosphate 101.6 kg as a dose per 0.45 ha of banana orchards in the Tamil Nadu State. The manurial scheme followed in Tanjore district is 101.6 kg of ammonium sulphate and 453.5 kg of groundnut cake per 0.45 hectare.

Cheema *et al.* (1954), in the Maharashtra State recommended top-dressing of the mixture consisting of castor-cake 1.8–2.2 kg, ammonium sulphate 0.67 kg, potassium sulphate 283–312 g and superphosphate 312–340 g per stool. Other oilcakes may also be used in addition to the above at the rate of 2.7–3.6 kg per stool twice or thrice a year. The same authors have also reported a popular practice in the Cauvery Delta where application of 101.6 kg of ammonium sulphate per 0.45 hectare in April-May, i.e., two months after planting is done, followed by an application of 453.5 kg of groundnut cake and 101.6 kg of ammonium sulphate in the fifth or the sixth month. The third and the last application is made in the ninth month which is similar to the first.

In some parts of Malabar (Kerala) handful of ash is added to each pit followed by 9.0 kg of green leaves of forest trees, and 2.2 kg of ash applied to the plants when they have put forth three to four leaves. This is followed by larger dose of the same when the plants are three- to four-month-old.

At Sabour (Bihar) the best manurial dose for banana was found to be the one consisting of 1.12 kg of ammonium sulphate and 0.9 kg of potassium sulphate per stool.

In West Bengal the common practice is said to be to intercrop banana during the first year of its planting with egg-plant which is manured with 3,732–5,598 kg of cowdung and 186–224 kg of mustard oilcake per 0.45 hectare, the manure being partly consumed by the banana plant.

Banana should be manured from early stages. Doses should be split up and a number of applications per season should be

made. Manures and fertilizers may either be broadcast over the whole area or on a metre around the stool. They may be concentrated in trenches between the stool and covered over with soil. Fertilizers should be spread in the area about 60 cm wide around the plant at a distance of 30 cm from the base and 5 cm to 7.5 cm below the surface. Sometimes, it is broadcast evenly in a ring 81 cm wide around the plants and incorporated well by hoeing 5 cm to 7.5 cm deep.

Papaya. The tree requires plenty of manure in one form or the other, as it bears heavily and throughout the year. In Maharashtra all sorts of manures, like farmyard manure, sheep-dung, wood-ash, bone-meal and oilcakes are used with success.

In northern India, the first dose of manure is given when the pit is filled up with 18.1–22.0 kg of farmyard manure and 1.3 kg of bone-meal. A second application at the rate of 36.2–45.3 kg of well-rotted farmyard manure per plant is given about four months after transplanting. Manure is again applied in about the same quantity when the plants are about a year old. In addition to this a fertilizer mixture consisting of three parts by weight of superphosphate, one part ammonium sulphate and 1.5 parts of potassium sulphate at the rate of 0.9 kg per tree should also be applied.

Manurial experiment conducted at Sabour has revealed that nitrogen in the form of ammonium sulphate has given better results than farmyard manure and *neem* cake. Though N and NPK showed no difference on growth the effect on yield was significantly better in the latter case.

In the Deccan, about 18.1 kg of farmyard manure is usually applied to each pit, while planting seedlings. A second dose of manure at the rate of 36.2–45.3 kg of farmyard manure is given to each bed about four or five months after transplanting, just about the time of flowering. The third dose of about the same quantity, as the second, is applied when the trees are about a year old, preferably at the commencement of the rains.

The best time for applying manures in south and western India is the beginning of south-west monsoons from May to July and again in the cold weather from November to December. The respective season in north India will be July-August and February-March.

The manure should be broadcast evenly in the basin and incorporated well by digging with a hand implement taking care that the roots, which are very near the surface, are not disturbed.

Guava. According to Rangacharlu (1954), good results were obtained at Kodur by applying 90.7 kg of leaf compost and 3.1 kg each of groundnut cake and ammonium sulphate per tree each year, thus applying about 1.8 kg of nitrogen.

Gandhi (1957) recommended 11.3 kg of well-ratted farmyard manure to an one-year-old tree. This quantity should be increased by 11.3 kg every year up to the end of fourth year, when it becomes 45.3 kg per tree. From the fifth year onwards, the same dose should be repeated every year.

Cheema *et al.* (1954) reported that 1.3–1.8 kg of castor-cake and about 18.1 kg of cattle manure per bearing tree per annum gave very good results in Karnatak. In Baroda a small quantity of common salt is also added to each pit along with 0.11 kg of castor-cake. These manures are applied to counteract the white ant trouble which is very common in Gujarat.

Farmyard manure should be applied after the rainy season and readily available nitrogen just before the flowers are set.

Litchi. No research work has been done in India on the manurial requirements of litchi plants. In Bihar, which has the highest acreage of litchi cultivation in this country, little or no manure is applied as the plants are grown in naturally rich soils. However, 22.6–226 kg of farmyard manure or leaf-mould per tree, depending on the age of the tree, are recommended. Vyas (1938) recommended application of 2.7 kg of castor-cake or 1.8 kg of *neem* cake, 1.8 kg of bone-meal and 3.7 kg of wood-ash per tree in December when new shoots begin to appear.

It is advisable to apply 37.3 kg of farmyard manure, 1.8–2.7 kg of lime, 1.8–2.7 kg of bone-meal and 4.5–5.4 kg of ash per pit at the time of planting. One-year-old plant should receive a fertilizer mixture consisting of 18.6 kg of farmyard manure, 1.8 kg of ash and 0.9 kg of castor-cake. These doses ought to be increased annually by 9 kg of farmyard manure, 0.9 kg of lime, 0.45 kg of bone-meal, 0.45 kg of ash and 0.45 kg of castor-cake till the trees are fully grown. A full-grown tree should receive 93.25 kg of farmyard manure, 4.6 kg of lime, 2.7–4.6 kg of bone-meal, 4.6–7.4 kg of ash and 4.6–7.4 kg of castor-cake, depending upon the age and spread of the tree, and general condition of the soil.

Manuring should be done once a year during October-November before the new shoots begin to appear.

It is important to note that litchi has a shallow root system and hence the manure mixture should be spread under the dip of the tree and forked well into the ground.

Loquat. No experimental data are available on the manurial requirements of loquat in this country. But it is certain that it is a heavy feeder, tends to exhaust the soil and requires generous manuring. It is reported that green manuring during the rains is desirable. Younger plants should receive 22.6 kg of farmyard manure and 0.45 kg bone-meal. For a full-grown tree, 45.3 kg of well-rotted farmyard manure mixed with 2.2 kg of bone-meal and 4.5 kg of wood-ash are recommended annually.

This should be applied in June in the light rainfall tracts and in October in the heavy rainfall areas. The tree starts bearing heavily from the seventh year onwards and hence manuring should be done twice a year.

Ber. Barakzai (1920) stressed the importance of manuring *ber* trees and reported that about 1.8 kg of salt should be given to each tree annually along with manure. Gokhale (1944) considered an application of three to four baskets of farmyard manure per tree desirable. Singh (1957) suggested application of four to five baskets of farmyard manure per tree at the advent of the rainy season. It has been found useful in increasing the yield and improving the size and quality of the fruit.

In western India *ber* plants are manured soon after the buds sprout at the rate of two to three baskets (18.1–27.2 kg) of farmyard manure. At the beginning of the monsoon 0.9 kg of common salt is given to each tree.

Manures and fertilizers are broadcast evenly on the surface soil 60–90 cm away from the tree trunk, and incorporated well into the soil by hoeing and digging.

Temperate fruits. Very little work has been done on the manuring of hill fruits in this country. However, under normal conditions nitrogen should be added at the rate of 0.04 kg for each year of tree age. Superphosphate and potash may also be applied at this rate when needed. The usual practice is to apply a mixture of one basket of farmyard manure, 0.1 kg each of ammonium sulphate and superphosphate per tree when less than about three-year-old, with double the above quantity of each for trees three to ten years of age. After this age, the annual application consists of three bushels of cattle manure and 0.45 kg each of ammonium sulphate and superphosphate. Dass recommended

20 cartloads of farmyard manure or compost per hectare per annum.

Manures and fertilizers may be applied any time during the dormant season.

Nitrogenous and potassic fertilizers should be broadcast by hand under the spread of the trees and forked well in the soil by hoeing. Superphosphate should be placed 7.5 to 10 cm below the soil surface in lumps around the tree.

VEGETABLES

According to the growing season, vegetables have been divided into two groups—winter or *rabi* vegetables, and summer or *kharif* vegetables. The first group comprises cole crops, like cauliflower, cabbage, knol-khol, etc., root crops, like carrot, radish and turnip, etc.; leguminous crops, like garden pea and pot-herbs, and greens like spinach, fenugreek, etc. The second group includes solanaceous fruits, like tomato, egg-plant, malvaceous crops, like lady's finger, vine crops, like pumpkin, bottle-gourd, summer squash, *tinda*, bitter-gourd, sponge-gourd, snake-gourd, etc., and leguminous crops like cluster-bean, etc.

Winter vegetables. Cauliflower requires very heavy manuring. Purewal (1957) recommended at least 40.64 tonnes of farmyard manure, 93.25 kg each of superphosphate and potassic sulphate per 0.45 hectare at the time of preparing the field for transplanting. 166.3 kg of ammonium sulphate per 0.45 hactare should also be added as a top-dressing in three doses—37.3 kg after the seedlings have set in the field, 93–112 kg three to four weeks after the setting of seedlings and 37–56 kg when the heads have started to form.

From the work done at Sabour it has been established that cauliflower crop should receive 27.2 kg of nitrogen, 45.3 kg of phosphorus and 36.2 kg of potash per 0.45 hectare.

Cabbage has been reported to give very good results when manured with 36.2 kg of nitrogen, 27.2 kg of phosphorus and 27.2 kg of potash per 0.45 hectare.

For cabbage, 933–1,190 kg of farmyard manure per 0.45 hectare are recommended before planting 74 kg of superphosphate at the time of final preparation of seed-bed and 74.6 kg of ammonium sulphate when the plants have set. Chonkar (1961) from Sabour reported that for higher cabbage production per 0.45 hectare, a starter solution consisting of urea or carbide, potassium sulphate and single superphosphate (1:1:2) should be given. 1.3 kg of this should be mixed with 227 litres of water and 0.28–0.56 litre of this is to be applied per plant. Mehta reported that cabbage and cauliflower each requires about 36.2–56.6 kg nitrogen which can be supplemented with 7,460 kg of well-rotted farmyard manure and 74–112 kg of ammonium sulphate. For root crops, he advocated about 10, 160–15,240 kg of well-rotted manure, 45.3 kg of potash and sufficient quantity of phosphorus. Purewal (1957) recommended a light dose of 8 to 10 tonnes per 0.45 hectare of farmyard manure, 74.6 kg of superphosphate and 93 kg of ammonium sulphate to the soil before preparing it finally for the seed-bed. Ammonium sulphate at the rate of 46 kg as second dose should also be given as top-dressing at the time of knob formation.

Peas should be manured with 8 to 10 tonnes of farmyard manure and 93 kg of potassium sulphate per 0.45 hectare. A light dressing of ammonium sulphate at the rate of 37.3 kg per 0.45 hectare may be given at the time of pod formation.

For winter pot-herbs and greens, Purewal (1957) recommended 15.24–25.40 tonnes of bulk manure per 0.45 hectare. A top-dressing of ammonium sulphate at the rate of two to three maunds per 0.45 hectare should be made. Mehta suggested that these crops require about 34–45.3 kg of nitrogen.

Onion crop requires 13.24–20.32 tonnes of farmyard manure and 181.4 kg of superphosphate. In some areas the general practice is to apply 25 cartloads along with 90.7 kg of superphosphate and five cartloads of wood-ash per 0.45 hectare. A top-dressing of 181.4 kg of ammonium sulphate or about 453.5 kg of oilcake per 0.45 hectare should be done 20 days to one month after planting.

Chonkar (1961) reported that a starter solution consisting of ammonium phosphate, magnesium sulphate, calcium nitrate, potassium nitrate and single superphosphate (2:1:1:1:2) proved to be very useful in increasing onion yield. One kg of this mixture mixed with 227 litres of water and 0.28–0.56 litre of it should be given to each plant.

Manurial trial at Sabour confirmed the superiority of the dose of 18.1 kg nitrogen and 18.1 kg potash applied to 0.45 hectare. Manuring of garlic is done as in the case of onion.

Heavy manuring in case of potato is always a paying proposition. It requires about 68–90 kg of nitrogen per 0.45 hectare. Half of this nitrogen should be in the form of organic and the remaining half in the fertilizer form. 15.24 tonnes of well-rotted farmyard manure, 186 kg of ash and 560 kg of castor-cake per

0.45 hectare should be thoroughly incorporated in the soil. Superphosphate at the rate of 112–186 kg per 0.45 hectare may be applied behind the plough (i.e., in furrows) during the final ploughing. During earthing up 186 to 373 kg of castor-cake and 149 kg of ammonium sulphate should be thoroughly mixed with the soil.

Summer vegetables. Among cucurbits, musk-melon, long melon (*kakri*), cucumber (*kheera*) and bitter-gourd should be manured with about 20.32 tonnes of farmyard manure per 0.45 hectare. Ammonium sulphate at the rate of 55.8–74.6 kg may be applied as a side-dressing when the fruits have set. In the case of bottle gourd and pumpkin, heavy manuring may be done only in patches leaving the rest of the field unmanured. Each patch is deeply dug and one basket-load of 9.3 kg of well-rotted farmyard manure together with 56.6 each of ammonium sulphate and superphosphate should be thoroughly incorporated in the soil in the rainy-season planting. For summer-season planting half the amount is needed. Water-melons need comparatively light manuring and 10.16 tonnes of farmyard manure may be added while preparing the land for seed-bed. Ammonium sulphate may be applied as top-dressing at the rate of 55.8–74.4 kg per 0.45 hectare. The same amount of manures and fertilizers may be given to *tinda* also.

Lady's finger (okra or *bhindi*) should be manured with 20.32 tonnes of farmyard manure per 0.45 hectare. A side-dressing of ammonium sulphate at the rate of 55.8 kg per 0.45 hectare is given when the plants commence pod formation.

Pocha and his associates (*cf.* Anonymous, 1952) reported that application of sodium nitrate or ammonium sulphate at the rate of 34–45 kg per 0.45 hectare, when the fruits begin to develop, has given excellent results. Nitrogen, phosphorus and potash each at 18 kg per 0.45 hectare has been found very effective in increasing the yield of tomato crop. Ghonkar (1961) advocated starter solution comprising calcium nitrate, potassium nitrate and single superphosphate (1:1:3) when 1.8–2.2 kg of it is mixed with 227 litres of water and 1 pint of this mixture is given to one plant.

Brinjal does best on rich soil and 10.16–12.18 tonnes of farmyard manure should be thoroughly incorporated in the soil before setting the plants in the field. The crop needs about 34–45 kg nitrogen, and if sufficient manure is not available it can be supplemented with ammonium sulphate and castor-cake. Ash may also be added at the rate of four cartloads per 0.45 hectare.

Cluster bean is a leguminous crop and hence ordinarily does not require much of manuring.

Manuring of Field Crops

The production of crops year after year on the same land results in a progressive drain on the nutrients. For example, a good crop of potato is reported to remove about 54.4–72.5 kg N, 11.3–13.6 kg P_2O_5, 90.7–113.3 kg K_2O, 27.2 kg CaO, 13.6 kg MgO, and 4.5–5.4 kg S, apart from the micro-nutrients. Similarly, other crops obtain from soil varying amounts of nutrients depending on the plant species, duration of the crop, climatic factors and fertility status of soil. No soil, howsoever rich, therefore, can sustain crop growth indefinitely without replenishment. With the necessity for obtaining bigger crops to meet the requirements of growing human population, use of high-yielding varieties, expansion of irrigation and adoption of better cultural techniques, and the rate of nutrient removal is becoming increasingly greater and the need for manuring to replenish the deficient nutrient or nutrients more and more insistent.

The value of dung, farmyard manure, green manuring, etc., to restore soil fertility and act as all-round soil amenders has long been recognized. Liming is also an old practice in humid areas in Western countries. It was only towards the middle of the 19th century that Liebig stressed the necessity of adding minerals to the soil to replenish the heavy losses resulting from crop growing (Law of Restitution). The Rothamsted experiments by Lawes and Gilbert demonstrated the need for addition of nitrogenous compounds at least for the non-leguminous crops and focussed attention on the usefulness of phosphatic and potassic fertilizers alone from amongst a wider array of minerals which Liebig recommended. The early studies and subsequent work has established that N, P and K are the most important and may justifiably be called the 'BIG THREE.' in manuring. They have profoundly influenced the development of fertilizer industry on the one hand, and stimulated research on plant nutrition and the fertilizer requirements of crops on the other. Consequently, certain basic principles of manuring have been established and knowledge of the judicious use of fertilizers and manures for increased productivity and maintenance of soil fertility has grown.

The scientific basis of manuring consists in applying to the soil, in required quantities, the deficient nutrient or nutrients, in order to ensure a good level of yield. This follows from the earlier view that yield is limited by the nutrient in 'relative minimum' and will increase as the level of the deficient factor rises (Law of Minimum) until another factor becomes limiting. It has been revealed by controlled experiments that when more than one nutrient limit growth and consequently yield, the increase in the level of either one of them often produces only a small or even negligible effect, while maximum returns follow simultaneous increases in the levels of all of them in balanced proportion (Interaction of Factors). The use of balanced fertilizers containing the major nutrients liable to be commonly deficient is, therefore, advocated. For economic use of fertilizers, however, it is necessary to determine the nutrient or nutrients actually limiting in a given situation.

The increases in yield with the increments in the level of a deficient factor may be linear within a narrow range only, but commonly follow the 'Law of Diminishing Returns'. Since manuring costs are proportional to the size of dressing, the optimum dressing is the one which maximizes the net returns and not necessarily the one which maximizes yield.

Based on the results of trials on cultivators' fields, and those conducted by Central Institutes and the State Departments of Agriculture, suggestions are available for manuring of many of the crops, which are considered here. Where no experiments have been conducted, broad indications based on experience of agricultural workers and farmers have been given.

PADDY

In India, paddy is grown under a wide range of soil and climatic conditions. The most important soil property for successful paddy production is its ability to hold water on the soil surface. Therefore, fine-textured and less-permeable soils and low-lying areas are usually more suitable. It can tolerate a fairly wide range of soil pH (4.0–8.4), although the optimum pH ranges between 5.0 and 6.5. As paddy has high water requirements and can grow under conditions of standing water, it has a fair tolerance to salinity.

It is grown almost in all the States of India, including Jammu and Kashmir, but it is mostly grown in areas of high rainfall in the States of Assam, Bihar, West Bengal, Orissa, Andhra Pradesh, Kerala, Madhya Pradesh, U.P. and Tamil Nadu. A considerable proportion of paddy crop is irrigated.

Adequately nourished, the crop is capable of producing high yields. Farmers are alike to the importance of farmyard manure, tank silt, etc., and apply these to the extent available. In southern States, green manuring *in situ* with legumes, such as *dhaincha*, is adopted by farmers to a considerable extent. Green manuring with tree loppings and, other perennial plants, such as *Ipomoea carnea*, is also a fairly common practice in these states, especially in areas where two or three crops are raised on the same field in a year. There is a growing consciousness of the need for fertilizer use in addition to organic manures for increased production of rice. However, only a small proportion of the crop at present receives fertilizers. The crop is under-nourished and is subject to nutrient deficiencies of varying intensity. Nitrogen deficiency results in poor and stunted growth, reduced tillering, pale and yellowish appearance of leaves, small ear-heads, and ultimately low production. Phosphate-deficient plants are stunted with small-sized, dark-green leaves bunched together. Their primary roots are elongated and deep reddish in colour. Tillering and production of secondary roots is suppressed.

Potassium deficiency is characterized by stunted growth, short and soft stems, and blue-green leaves with bent ends.

Responses to fertilizers. Of the three nutrients the deficiency of nitrogen is widespread. Phosphate deficiency is also fairly common; potassium deficiency is localised. This is borne out by results of relative responses to fertilizers in numerous experiments on cultivators' fields. The average responses to nitrogen, phosphorus and potash each at 22.4 kg|ha have been found to be 3.0, 2.2 and 1.4 q|ha respectively.

The application of nitrogen and phosphorus at the rate of 22.4 kg per hectare gave substantial response on all soils (Table 63). The price of paddy to potash is about one-half as compared with the price of nitrogen and phosphorus per unit of nutrient. The application of potassium would, therefore, be remunerative in some of the areas.

A study of the results according to the different agro-climatic regions also revealed similar results (Table 64).

Under better management and assured water supply, favourable responses to higher levels of both nitrogen and phosphorus have been obtained. The doses of nitrogenous fertilizers to be applied would depend on whether the crop follows green manuring or not. 40 kg N|ha, in the absence of green manuring and 20 kg N|ha with green manuring, in addition to 20 kg P_2O_5|ha in either case may be applied. Besides, the application of 20 kg P_2O_5|ha is advisable in Kerala, Bihar and other areas where measurable responses to potassium have been obtained.

TABLE 63. RESPONSE OF PADDY (Q|HA) TO NITROGEN, PHOSPHATE AND POTASH (EACH AT 22.4 KG|HA) IN DIFFERENT SOIL GROUPS

Soil group	No. of trials	Av. yield in control plots	N	P_2O_5	K_2O
Alluvial	933	12.2	3.7	2.0	1.2
Black	130	13.6	2.7	2.1	0.8
Coastal alluvial ..	451	14.6	2.4	1.9	1.4
Hilly	42	10.6	1.6	1.2	0.6
Laterite	239	15.2	3.0	1.7	1.6
Red	624	15.2	3.3	2.6	1.7
Red and black ..	89	16.0	3.5	3.0	2.5
Other alluvials ..	93	10.3	2.2	1.6	0.8
Terai and submontane	90	9.4	2.5	1.6	1.1

The rates of fertilizers which are recommended for application to rice in India are much lower than those actually used in Japan and other countries, where high hectare-yields are obtained. This is because the yield potential of existing Indian varieties is low, as they cannot utilize heavy fertilization and are prone to lodging. *Indica-japanica* hybrids have been developed and are being tested for selection of those which may stand up to high levels of manuring. The fertilizer recommendations will, therefore, need to be revised upwards, with the availability of lodging resistant varieties.

Effect of different nitrogenous fertilizers. It is generally believed that ammoniacal form of nitrogen is more effective than in nitrate form in paddy soils grown under anaerobic conditions. However, experiments on the relative performance of different nitrogenous fertilizers, i.e., ammonium sulphate, urea and ammonium nitrate, have shown them to be more or less, equally effective (Table 65). In recent years new fertilizers, such as C.A.N., urea, ammonium sulphate nitrate, ammonium chloride, have been pro-

TABLE 64. RESPONSE OF PADDY TO NITROGEN, PHOSPHATE AND POTASH ACCORDING TO AGRO-CLIMATIC REGIONS

Main region	Agro-climatic region	States included	No. of districts where trials were conducted	No. of trials	Average yield control plot	Response to 22.4 kg|ha N	P	K
Himalayan	Western Himalayas	Himachal Pradesh and Punjab	3	39	10.7	1.5	1.2	0.7
	Eastern Himalayas	Assam	7	119	15.7	3.1	2.8	2.8
Northern Plains	Lower Gangetic	Bihar, West Bengal and U.P.	22	818	11.9	2.8	1.4	0.9
	Trans-Gangetic	U.P.	10	269	10.8	2.6	1.5	1.0
	Upper Gangetic	Punjab and Delhi	4	660	14.1	3.9	2.2	2.1
Peninsular Hills and Plateau	Northern Central Hills and Plateau	Madhya Pradesh	3	39	8.0	3.1	2.3	2.1
	N. E. Plateau	Bihar, Orissa and Madhya Pradesh	12	320	13.8	3.9	3.4	2.2
	South Deccan	Andhra Pradesh and Mysore	10	451	16.4	2.6	2.1	1.2
Western Ghats and Coastal	Malabar Konkan	Kerala	4	325	14.1	2.4	2.0	1.3
Eastern Ghats and Coastal	Northern Madras and Orissa	Madras, Orissa and Andhra Pradesh	10	231	14.1	2.8	1.7	1.6
	South Madras	Madras	7	175	16.9	2.2	1.8	1.2

TABLE 65. RELATIVE EFFICIENCY OF DIFFERENT NITROGENOUS FERTILIZERS (Response in q|ha)

Experimental station or centre	State	Control yield (q|ha)	Ammonium sulphate at 22.4 kg|ha	Ammonium sulphate at 44.8 kg|ha	Urea at 22.4 kg|ha	Urea at 44.8 kg|ha	Ammonium nitrate at 22.4 kg|ha	Ammonium nitrate at 44.8 kg|ha
Karjat	Maharashtra ..	28.9	1.3	10.0	1.5	7.1	4.1	6.3
Ponnampet	Mysore ..	33.4	1.6	2.5	3.6	4.9	4.8	2.3
Shimoga	Mysore ..	14.1	5.2	9.6	4.6	7.0	..	..
Sahaspur	Orissa ..	21.5	6.2	9.5	5.8	6.0	2.7	5.2
Barapali	Orissa ..	28.8	..	3.3	..	3.9	..	..
Hiragachi	West Bengal ..	31.1	3.3	2.3	1.0	2.2	0.5	4.3
Mankhanda	West Bengal ..	15.7	5.1	8.7	4.9	17.4	3.7	3.8
Maruteru	Andhra Pradesh	37.5	8.3	3.2	7.5	12.9	1.6	4.2
Chalvai	Andhra Pradesh	33.0	1.9	2.4	1.1	1.2	..	..
Aduthurai	Madras ..	23.6	3.9	4.7	3.3	4.3	..	..

duced in India; the one locally available should be used by adjusting the time and the method of application.

It is still believed in certain quarters that continued use of fertilizers, particularly ammonium sulphate, adversely affects the soil. The truth is that continued use of ammonium sulphate alone results in the rapid depletion of the phosphorus resources of the soil with the result that in due course, application of N in the absence of P gives little or no response. As a result of series of long-term experiments, ammonium sulphate has been applied continuously in varying doses from 22.4–100.89 kg N|ha alone and in combination with compost and lime. Increasing response was obtained up to 45 kg N|hectare without any adverse effect on soil.

Deep placement of nitrogenous fertilizers: Generally, the nitrogenous fertilizers in India are broadcast at the time of the final puddling, just before transplanting of paddy. By this method, considerable amount of nitrogen applied is lost through leaching and de-nitrification process. These losses can be considerably reduced by sub-surface application of a nitrogenous fertilizer. The result obtained at the C.R.R.I., Cuttack, are given in Table 66.

TABLE 66. RESPONSE OF PADDY (IN KG|HA) TO SUB-SURFACE AND SURFACE APPLICATION OF 22.4 KG|HA OF AMMONIUM SULPHATE

Year	Control (kg)	Response to 22.4 kg|ha	
		Surface	Sub-surface
1949–50	1,733	169	259
1950–51	2,036	253	315
1951–52	2,421	98	230
1952–53	1,646	251	372
Mean		193	294

Table 66 indicates that sub-surface application at the time of sowing gives a higher response as compared to surface application. As a result of several such studies it has been estimated that response with deep placement (sub-surface) of ammonium sulphate (22.4 kg N|ha) is comparable to double dose of ammonium sulphate (44.8 kg N|ha) applied broadcast on the surface.

Time of application of nitrogenous fertilizers: Because of anaerobic conditions under which paddy is grown and the nature

TABLE 67. RESPONSE OF PADDY (Q/HA) TO DIFFERENT TIMES OF NITROGEN APPLICATION

Station or centre	Full dose			1 dose before planting and ½ at tillering	½ dose at planting and 1 at tillering	⅓ dose before planting, ⅓ at tillering and ⅓ at flowering	⅓ dose at planting, ⅓ at tillering and ⅓ at flowering	Control yield
	Before planting	At planting	At tillering					
Karjat (Maharashtra)	8.3	9.2	8.6	8.5	10.2	8.7	8.5	..
Nasirpur (Punjab) ..	3.3	3.6	..	3.9	..	..	..	..
Mankhanda (W. Bengal) ..	2.6	2.8	3.1	2.5	4.0	2.5	2.7	15.9
Hiragachi (W. Bengal)	2.6	3.6	2.4	3.6	3.4	3.9	4.8	25.5
Aduthurai (Madras) ..	8.9	8.6	9.0	7.4	6.3	6.4	6.8	27.0

of the crop itself, the efficiency of different nitrogenous fertilizers depends considerably on the time of its application. Ammoniacal forms can be applied at transplanting or sowing time. Nitrate forms should preferably be top-dressed. Other forms may be given as split application. The field should be well-bunded to prevent the movement of water from one field to the other, so that the fertilizer is not washed away. Recommendations regarding the best time of application also depend upon the paddy varieties and nitrogen content of the soil. A summary of the results on time of application obtained at different centres in the country is given in Table 67.

Relative efficiency of phosphatic fertilizers and their method of application. Of the phosphatic fertilizers, the water-soluble one, i.e., superphosphate, gives slightly better response than others. Phosphatic fertilizers are always applied as basal dressing. Top-dressing of phosphatic fertilizers is not recommended.

Liming. Rice can tolerate soil acidity and also soil alkalinity. However, liming can play a decisive role in obtaining high yields and the response to applied phosphorus on acid soils, as in parts of Kerala.

WHEAT

Wheat is grown on normal soils of varying texture ranging between sandy loam and heavy black soils, in the plains of India and on acid or acidic soils in the hills. The crop is largely cultivated in the Indo-Gangetic plains and the central and the western parts of the country. Amongst *rabi* crops, wheat enjoys preferential treatment with regard to soil, irrigation and cultural practices. Medium and fine-textured deep soils are preferred, and about 30 per cent of the area is irrigated.

The crop generally follows cultivated *kharif* fallow, and in some areas receives farmyard manure. In recent years double-cropping is being increasingly practised and crop is grown after maize, *kharif* fodders or millets.

Effect of fertilizers. Wheat is generally responsive to nitrogen and phosphorus applications, particularly the former. The response to potassium has not been obtained in majority of the cases. The results of trials conducted on cultivators' fields all-over India, summarized according to the different agro-climatic regions, are given in Table 68.

TABLE 68. RESPONSE OF WHEAT (Q|HA) TO N, P AND K ACCORDING TO AGRO-CLIMATIC REGIONS

Main region	Agro-climatic region	States covered	No. of districts covered	No. of trials	Average yield of control plots	Response to 22.4 kg|ha N	Response to 22.4 kg|ha P_2O_5	Response to 22.4 kg|ha K_2O
		Irrigated						
Northern Plains	Lower Gangetic	Bihar, West Bengal and U.P. ..	15	507	11.7	3.8	1.9	1.0
	Upper Gangetic	U.P.	12	746	13.7	3.7	2.3	1.4
	Trans-Gangetic	Delhi, Punjab ..	11	355	16.2	3.9	3.2	1.5
	Desert	Rajasthan ..	2	55	12.3	3.2	1.7	1.2
Peninsular Hills and Plateau	N. W. Hills	Rajasthan ..	2	51	9.5	2.0	0.8	0.3
	Northern Central Hills and Plateau	Madhya Pradesh	3	26	9.0	2.6	1.3	1.7
	N. E. Plateau	Bihar, Orissa, M.P.	9	166	10.4	3.9	2.8	2.1
		Unirrigated						
Himalayan	Western Himalayas	Punjab, M.P.	4	194	9.8	2.2	1.9	1.0
	Lower Gangetic	Bihar, West Bengal	10	220	8.8	2.4	1.2	0.9
	Trans-Gangetic	Punjab	7	82	9.5	3.9	1.2	0.9
Peninsular Hills and Plateau	N. E. Plateau	Bihar, Orissa and M.P.	2	35	11.6	3.5	2.9	2.3
		Average ..	23	531	9.4	3.4	1.3	0.9

These results clearly reveal that wheat responds well to nitrogen, both under irrigated and non-irrigated conditions. The response to phosphorus is also appreciable though lower than that of nitrogen, and that to potassium is quite marked in Bihar, Orissa and Madhya Pradesh, both under irrigated and non-irrigated conditions, but not in other States.

In some cases, increasing responses have been obtained with N up to 67.2 kg|ha and P_2O_5 up to 110.3 kg|ha. Except when a soil-exhausting *kharif* crop precedes wheat, application of such high doses of nitrogenous fertilizers is risky as the cultivated wheat varieties in India are prone to lodging. Short and stiff-strawed Mexican varieties are under test to select those which resist lodging under conditions of high soil fertility and give high yield. With this development application of higher rates of fertilizers may be possible. For the present, applications have to be limited to about 20–25 kg N, and 20–25 kg P_2O_5 per hectare under irrigated conditions when the crop follows *kharif* fallow; the dose of N could be doubled if the previous crop is *jowar*, maize or *bajra*. Under non-irrigated conditions, about 15–25 kg N and 15–25 kg P_2O_5 per hectare could be applied.

Time and methods of application of fertilizers. Phosphatic fertilizers should be applied before sowing. The same applies to potassic fertilizers where needed. Nitrogenous fertilizers can be applied to irrigated wheat at the time of sowing, at first irrigation or in split application. In the case of split application, usually half the recommended dose is applied at sowing time and the balance at the first irrigation. Early application generally increases the weight of straw to a greater extent than the later or the split application, and may induce lodging if high doses are used. Little difference in the response to different times of application of nitrogen on the yield of grain has been found, but split application will generally be preferable to early application under most conditions, especially with long- and soft-strawed varieties. In the case of the non-irrigated wheat the phosphatic as well as the nitrogenous fertilizer must be applied at or just before sowing time.

Phosphatic and potassic fertilizers if used should be drilled at or before sowing time. The date of nitrogenous fertilizer to be applied at sowing could be mixed with the phosphatic fertilizer before drilling. If surface soil is moist enough to permit sowing by *kera* method (cropping seed by hand in furrows opened by plough) fertilizer mixture could be drilled through a *pora* (a funneled tube attached to the plough). If the seed has to be drilled by *pora* method for want of sufficient moisture in the surface soil at sowing, a side and deep placement of the fertilizer will be desirable either with a combined seeding-*cum*-fertilizer drill or by going over the field twice, once for drilling fertilizers and thereafter for drilling seed. In some places, as on heavy soils of Madhya Pradesh, mixture of nitrogenous fertilizer at half rate and full dose of phosphatic fertilizer are mixed with seed and drilled together. The practice needs to be evaluated in different soils under different conditions of moisture at sowing to fix the optimum safe dose of fertilizers that can be drilled with seed.

Phosphate could be applied to wheat directly as indicated above or *via* the legume. This has proved to be a very good practice at the I.A.R.I., New Delhi. Phosphatic fertilizer applied to berseem increases the yield of fodder appreciably, and also benefits the succeeding wheat crop. If the wheat crop follows *kharif* legume, such as *guar*, green manured or removed for fodder, phosphate could be applied to the legume. If wheat follows green manuring, application of nitrogenous fertilizer is not normally necessary.

Fertilizer application in relation to irrigation: Irrigation influences the response to fertilizers. In the Simple Fertilizer Trials, the response of irrigated wheat to nitrogen and phosphorus was higher by about one q|ha as compared with non-irrigated wheat. There was no difference in the response to potassium.

In the experiments at the Model Agronomic Centre, Powerkheda, the effect of frequencies and intensities of irrigations were studied in relation to nitrogen and phosphorus levels at eight centres. The results obtained on heavy black soil at Powerkheda (M.P.) are given below.

Frequency of irrigation	Yield without N	Response to N at		Yield without P	Response to phosphate at		Remarks
		33.6 kg N/ha	67.2 kg N/ha		33.6 kg P_2O_5/ha	67.2 kg P_2O_5/ha	
2	13.2	4.7	7.0	11.6	6.4	6.7	Results of 2 seasons
3	12.2	6.5	11.1	11.3	8.4	9.3	
4	13.5	6.5	10.6	12.2	7.8	0.1	

The response of N and P was affected by the number of irrigations. The response increased when the number of irrigations was raised from two to three, but there was no further response when the number of irrigations was increased from three to four. The results of experiments on alluvial soil elsewhere also point to the improved fertilizer response with more frequent irrigations. Depth of water applications does not generally influence fertilizer response. In fact heavy irrigations of well-fertilized crop should be particularly avoided in the later stages of crop growth after ear emergence to minimize lodging hazards.

Fertilizer application in relation to other factors: The response to both nitrogen and phosphorus is higher when wheat is sown at the optimum time for a region or place. Late sowing or too early sowings generally give lower response to fertilizers. The response of the late-sown crop can be improved to some extent by increasing the seed rate.

For ensuring good response to fertilizers it is necessary that good germination and optimum crop stand is maintained. In white ant-infested areas insecticides for control of white ants should be used to prevent gappiness in stand.

Although crop is largely grown on soils having slightly acidic to alkaline reaction, some areas in hills, e.g., Kangra (Punjab) and Chota Nagpur Plateau, have acid soil. Liming is advisable when pH of the soil falls below 5.5. The dose of lime to be applied should be fixed on the basis of soil pH and texture of the soil. Lime should be broadcast about two weeks before the last ploughing.

As wheat does not tolerate soil salinity, and alkali soil conditions, and use of fertilizers to this crop on such soil will be wasteful, the crop should be substituted by salt-tolerant crops, e.g., barley under such adverse situations.

BARLEY

Barley is an important cereal crop under conditions which are not well suited for wheat. It can tolerate the adverse weather and soil conditions better than wheat. Relatively poor sandy soils are, therefore, relegated to barley. Barley is salt-tolerant and is, therefore, grown on saline and alkali soils as well. It is not grown on acid soils as it is very sensitive to soil acidity. Being early maturing, it can be sown late and can stand drought conditions better, even though it has relatively shallow and weak root system. The crop is usually not irrigated and is sown mixed with gram. The crop is rarely manured by the farmers.

The fertilizer requirements of barley are more or less similar to those of the wheat crop. The dose of fertilizer application depends on the purpose for which the crop is grown. If grown for malting purposes, the nitrogen content of the grain should be low and the starch content high. Therefore, under such conditions, barley should follow a soil-exhausting crop and N application should be rather low, not exceeding 10–15 kg N/ha. But the doses of P and K could be almost double the dose of N. When barley is grown for grain for human consumption or fodder, nitrogen application could be higher, about 25–30 kg/ha. The excess of nitrogen has, however, to be avoided as it causes lodging. Methods of application suggested for wheat also apply to barley.

Application of nitrogen at 22 kg/ha in the form of urea spray has also given good results in the recent experiments at the I.A.R.I., New Delhi.

MAIZE

Maize is sown with the commencement of rainy season in the plants of U.P., Bihar, Punjab, Rajasthan, Madhya Pradesh, Jammu and Kashmir, West Bengal and Gujarat, and harvested during September-October. In hilly areas, the crop is sown during March-May and harvested in August-September. In Andhra Pradesh and Maharashtra, apart from the rainfed crop, an irrigated crop is grown in the *rabi* season. *Rabi* maize has also shown promising results in experiments in Bihar and the practice may gain acceptance in this State and in other States where similar agro-climatic conditions exist.

The crop is grown on a variety of soils, ranging between the sandy loam and alluvial in the Indo-Gangetic plains and black soil in the Deccan. High-lying, well-drained fields are generally preferred for its cultivation in the rainy season as the crop is sensitive to water-logging. Though largely grown on soils of neutral to alkaline reaction, acid soils are also used for its cultivation in some areas such as Chhota Nagpur Plateau.

In the Indo-Gangetic plains, the important rotations including maize are maize-*senji*-sugarcane-wheat, maize-potato-tobacco or onion or calocasia or sugarcane, maize maize-early potato-late potato-*cheena*, and maize-potato-sugarcane-wheat. Thus, the crop generally follows a soil-exhausting crops such as wheat. Till recently, local varieties of varying durations have been used for the cultivation of this crop. Recently suitable varieties of hybrid maize have been developed. Two hybrids, Ganga-1 and Ganga-101, are recommended for the Indo-Gangetic plains of the Punjab, Madhya Pradesh and the foot-hills of Himachal Pradesh. The Ranjit hybrid is recommended for Rajasthan, northern Gujarat and Maharashtra, and the Deccan hybrid for Peninsular India.

The local maize varieties grown at present are often manured with farmyard manure. The consumption of fertilizers is rather low. Being a quick-growing crop, capable of producing heavy yields in a short period of 2.5–3.5 months depending upon the variety, the crop needs ready supply of nutrients in available form for its proper growth.

Deficiency of nitrogen is indicated by pale-green or yellowish-green appearance of leaves, stunted growth and reduced size of foliage. The yellowing and drying generally extends from the leaf midribs in widening bands towards the tips. Phosphorus deficiency is characterized by poor root development, purple colouration of leaves and delayed ripening. Potassium deficiency is shown by leaf discolouration followed by browning and scorching of the leaf margins.

Marked responses have been obtained to the use of nitrogenous fertilizers wherever moisture supply is not a limiting factor. Optimum dressings depend on the fertility status of the soil. In the case of hybrids, profitable returns have been obtained in experiments to N ranging between 80 and 160 kg and P_2O_5 between 45 and 90 kg per hectare. Application of a potassic fertilizer at 45–60 kg K_2O per hectare is also advisable. In recent experiments response to zinc has also been noted in the case of hybrid maize. In the case of ordinary maize the approximate fertilizer requirements for N, P and K will be about half as those for the hybrids.

Relative efficiency of different sources of nutrients. Experiments have shown that the response of maize to the different sources of N, viz., ammonium sulphate, urea, calcium ammonium nitrate, ammonium sulphate-nitrate, is more or less the same. However, there is an indication that ammonium sulphate-nitrate was slightly better than ammonium sulphate in isolated cases.

Time and method of application. The full dose of phosphatic and potassic fertilizers and one-half or one-third the total dose of nitrogen should be drilled in the soil and seed sown in the resulting furrows. The remaining dose of nitrogenous fertilizers should be top-dressed when the plants are about 15–20 cm high and again when the plants are 60–75 cm high. Deficiency of micro-nutrient Zn has been noticed in hybrid maize at the I.A.R.I. and the deficiency was corrected by spray application with zinc sulphate.

Factors influencing fertilizer response: Sowing of the crop with the commencement of the monsoon or a few weeks in advance is expected to give higher response to fertilizers than delayed sowings. The crop is sensitive to drought as also to waterlogged conditions. Provision of adequate supply of moisture through supplemental irrigation and provision for drainage of excess water are essential for obtaining high yields and high responses to fertilizers. The maintenance of optimum plant population is also important for obtaining high yields and response to fertilizers.

When grown on acid soils, as in Kangra (Punjab), Chota Nagpur, and Assam, the acidity should be corrected by liming on the basis of soil tests.

JOWAR

Jowar is grown as a *kharif* crop mainly in Maharashtra, Gujarat, Mysore, Andhra Pradesh, Madhya Pradesh and Uttar Pradesh. In parts of Maharashtra, Mysore, Andhra Pradesh, Gujarat and Tamil Nadu, *Jowar* is also a *rabi* crop. The crop is not as drought-resistant as *bajra*. It is, therefore, grown on areas receiving relatively assured rainfall and on soils of finer texture and with better moisture-retaining property than those relegated to *bajra*.

It is known to be a highly soil-exhausting crop. It has the capacity to grow rapidly and depletes the soil of the nutrients, particularly nitrogen, in a relatively short period. Perhaps no other crop is a better indicator of the low fertility of soil in terms of nitrogen as *jowar* crop. Although it can draw on soil nutrients effectively as evidenced by the reduced fertility of the soil cropped with *jowar*, the use of farmyard manure and fertilizer is necessary to maintain the soil fertility and assure reasonable yields. The general limiting factor under unirrigated conditions is, however, the moisture supply. Since, generally the crop is grown in areas where rainfall is usually adequate and the soils are retentive of moisture, the application of low doses of fertilizers is expected to be remunerative. Experiments conducted at the PIRRCOM centres have shown that the crop is responsive to application of fertilizers. In an agronomic trial at Bellary conducted during 1962-63, application of 9 kg N and 18 kg P_2O_5 gave the maximum yield of grain and straw. In an experiment at the PIRRCOM Centre, Dhadesugar, application of nitrogen at 13.6 kg and phosphate at 18 kg increased the yield of grain and fodder.

In view of these results, the application of fertilizers to *jowar* is desirable. To minimise the risk under unirrigated conditions, however, the fertilizer doses should be kept low. In general, 15 kg of N and 15 kg of P_2O_5|ha may be applied just before sowing. In case the crop shows deficiency symptoms of nitrogen, which are clearly recognizable in this crop, top-dressing of 15 kg N per hectare may be applied in areas where the failure of monsoon rains is infrequent. In the case of *rabi jowar*, grown under irrigated conditions, moisture supply is not a limiting factor. Therefore, 20 kg N and 20 kg P_2O_5 may be applied at the time of sowing followed by a top-dressing of nitrogen at the rate of 20 kg N|ha just before irrigation.

BAJRA

The crop is grown on soils of low fertility and low productivity, and in areas receiving low rainfall mainly as a rainfed, unirrigated crop. Largest areas lie in Rajasthan, Gujarat, U.P., the Punjab and the Deccan Plateau. It is grown on all types of soil. The unirrigated crop is generally grown mixed with pulses, castor, gingelly, etc., but irrigated crop is pure one. Rainfed *bajra* is rarely manured and the yields are low. Penning of sheep and goat is practised in some parts of the country. Irrigated crop is manured with farmyard manure.

The crop responds well to manuring. In an experiment on manuring of *bajra* at Palur (Madras), direct application of ammonium sulphate at 112 kg or groundnut cake at 560 kg and superphosphate at 56 kg per hectare doubled the yield. The application of these manures to cotton resulted in 40 per cent increase of the yield of the succeeding bajra. On irrigated crops, 67.20 kg N+50.40 kg P_2O_5 or 100.80 kg N+67.20 kg P_2O_5 in conjunction with compost at 5.70 tonnes and 56 kg K_2O gave significantly higher yields as compared with compost at 5.70 tonnes per ha. In Bombay, 67.20 kg N+44.80 kg P_2O_5 and five cartloads of farmyard manure per ha has been found to be the best combination.

Experiments conducted at PIRRCOM Centre, Ajmer, have shown that application of 44.80 kg N per ha enhanced the yield of *bajra* grain by 64.2 per cent, being 6.74 q|ha. An increase of about 19 per cent (2.01 q|ha) was obtained with the application of 44.80 kg phosphoric acid per ha. Nitrogen and phosphorus when applied alone showed good effects on *bajra* yield, but their combined effect was almost equal to that of the nitrogen application alone. Working out the economics of application of 44.80 kg N per ha, which gave the best results, it was seen that a net profit obtained was Rs 187.79, which is quite a reasonable return.

Recent experiments at the PIRRCOM Centre, Kanpur, have shown that foliar application of N at 11.2 kg N/ha was almost as effective as double the rate of soil application in grain yield and also increased protein content of *bajra*. But these results would need verification.

The response to unirrigated *bajra* depends on the amount and the distribution of rainfall. Since rainfall varies from year to year, application of high doses may not be always economical, although in individual years high response to doses as high as 45 kg N|ha and 45 kg P_2O_5|ha, consistent with economic returns may be obtained. It would be desirable to apply low doses of 10–20 kg N and 10–20 kg P_2O_5|ha. Under irrigated conditions double the doses may be applied. The fertilizers could be drilled at the time of sowing. If nitrogen alone is applied it could be broadcast.

RAGI

Ragi is grown mainly in Mysore and to a considerable extent in Tamil Nadu, Maharashtra and Andhra Pradesh. It is cultivated chiefly on red and light red soils as a dry crop. It is grown pure or mixed with a pulse crop. It is rotated with groundnut, or with sesamum, green gram and horse gram. In many cases no rotation is followed. Irrigated crop is often rotated with rice or with garden crops.

The crop is manured with farmyard manure at the rate of 15–20 cartloads and with tank silt at the rate of 10–15 cartloads per hectare. Penning of sheep is also practised in some areas. Some farmers also apply oilcake and fertilizers.

As soils on which *ragi* is grown are low in nutrients and organic matter, there is need to apply both organic manures as well as fertilizers, but moisture supply is the limiting factor under unirrigated conditions. This consideration necessitates adoption

of low doses of N, P and K. 15–20 kg|ha of each of the three nutrients may be applied to rainfed crops and double the doses to the irrigated crop.

Phosphate and potash should be drilled before sowing both in the unirrigated and the irrigated crop. Nitrogen should be applied as top-dressing after weeding under unirrigated conditions. Under irrigated conditions, half the dose of nitrogen could be applied at sowing and the rest top-dressed just after weeding.

PULSES

About 90 per cent of the area under pulses in India is unirrigated. The crops are deep-rooted and have low irrigation requirements. The commonly grown pulses may be divided into two categories: (*a*) those which are sown in the *rabi* season after the cessation of monsoon rains and grow under conditions of decreasing soil moisture, and (*b*) those which are grown in the rainy season and are subject to conditions of excess moisture or of deficient moisture at different times during the crop season. In the former category are included crops, such as gram, peas, lentil and *khesari*. The important crops included in the latter category are *Phaseolus* spp. (black gram, green gram, *moth*), *guar* and cowpeas. Red gram is a long-duration legume which is sown with the commencement of the monsoon rains and matures in the *rabi* season. Pulses may be grown as pure crop or mixed with other crops. The pulses grown in the *kharif* season are grown as mixtures with *jowar*, rice, maize and cotton. *Rabi* pulses are mixed with wheat, barley, linseed and rape and mustard. Some of the pulses, such as gram, *khesari* and green gram, are sown as *paira* or *utera* crops in rice fields, i.e., the seed is broadcast in the standing crop of rice a few days before the rice harvest.

Due to the pressure of root nodules these crops are more or less self-supporting in regard to their nitrogen requirements although some of them may profit from low (starter) doses of nitrogenous fertilizers. High doses of nitrogen depress nodule formation.

The activity of the rhizobia (bacteria) is influenced by nutrients, such as phosphate and calcium content, of the soil and soil pH. Soil acidity does not constitute favourable environment for nodule formation and the development of the bacteria. Therefore, these crops are grown on acid soils as in hilly and plateau areas (for example Chhota Nagpur Plateau) the soils must be limed to correct the acidity. Both on acid soils and on alkaline or neutral soils, phosphate is often the factor limiting the yields of these crops. Phosphate manuring is, therefore, the basis of manuring the pulse crops.

The fertilization of legumes with phosphate, not only assures the best performance of the pulse crop, but also leads to economy in the dose of nitrogen on the succeeding crop of non-legumes.

It has been observed in the Simple Fertilizer Trials that the residual effect to 33.6 kg, P_2O_5 per hectare applied to the preceding legume on the following rice was 1.1 q|ha. The residual response was equivalent to nitrogen application ranging from 7–30 kg per ha in about 60 per cent of the trials.

Method of application. For pure crops of *kharif* pulses grown during the rainy season or *rabi* pulses grown under irrigation, manuring presents little problem; a mixture containing low doses of nitrogen and high dose of phosphate can be drilled through a funnelled tube (*pora*) at plough-sole depth, and seed dropped (*kera*) in the resulting furrows. However, two or three special situations complicate the manuring programme: (*a*) some *kharif* pulses are sown mixed with other crops either in separate rows or intermingled within the rows or are broadcast between the rows of the main crop; (*b*) some of the *rabi* pulses such as *khesari* are sown by *paira* or *utera* method in standing crop of rice; and (*c*) *rabi* pulses, such as gram, are grown pure or mixed on conserved moisture inasmuch as the surface soil dries and the seed has to be drilled in the moist layer and furrows left open to ensure germination. Suggestions for manuring in these situations may be considered here.

When *kharif* pulses are sown with the seed of other crops, the average dose of fertilizers, depending upon the relative proportion of the area estimated to be occupied by the main and the subsidiary crop in the field, may be drilled and crops sown according to the normal practice. If the pulse and the other crop are sown in separate rows, it may be possible to manure the individual rows of the pulse crop with phosphates or phosphate plus a low dose of nitrogen separately; the fertilizer may be drilled and seed dropped with hand in furrows.

When the pulses are sown by *paira* method, it is not convenient to apply the fertilizer to the pulses. The only alternative is to apply an additional dose equivalent to the share of the pulse crop and drill the same at the time of transplanting or sowing of the rice crop.

The top-dressing of nitrogen applied to rice is also expected to leave adequate residual effect for the benefit of the legume.

In the case of *rabi* pulses grown on conserved moisture, where the soil surface has dried and the seed has to be drilled, it is equally important that the fertilizer, to be effective, is also drilled deep in moist soil layer. For this purpose the use of a combined seedling-*cum*-fertilizer drill, which carries the coulter for drilling fertilizer in front and that for drilling seed in the rear but a couple of cm to the side, is advisable to avoid direct contact of fertilizer with the seed. It is understood that in Madhya Pradesh, low doses of fertilizers and seed are mixed with seed before the two are drilled. Experiments on the maximum doses of fertilizers which can be drilled with seed need to be carried out under different soil conditions.

Brief descriptions of the individual pulses are given below.

Gram. Gram occupies the largest proportion of the area under pulses and is largely grown as a *rabi* crop on conserved moisture. In some parts, where rainfall is low, the crop is grown with irrigation and high yields are obtained. It is a soil-restorative crop and does not normally receive any manures and fertilizers, although it frequently follows soil-exhausting crops, such as *jowar*, maize, *bajra* and rice. Although the responses of this crop to manuring have been somewhat variable, it can be generalized that the crop responds to fertilizers. As the crop is grown on conserved moisture which progressively decreases during the crop season, only low doses need to be applied. Application of 10 kg N and 20–30 kg P_2O_5 per hectare would generally lead to increase in yield over a wide range of conditions, under non-irrigated conditions. Under irrigated conditions, the dose of phosphate could be almost double of that under non-irrigated conditions. When the crop follows a soil-exhausting crop, such as sorghum or maize, the use of nitrogen is expected to be specially beneficial. In some parts of the country as in Chota Nagpur (Bihar), where gram is grown on acid soils, application of lime according to the lime requirements is necessary.

Superphosphate may be considered to be the suitable source of phosphate under all conditions.

As the crop is grown in winter without irrigation, response to fertilizers depends on adoption of moisture conservation measures, such as contour-bunding, contour-ploughing, planking the soil, after cessation of rains. Timely sowing and deep placement of fertilizers in the moist layer of soil are also specially important for the effective utilization of the conserved moisture and improved fertilizer response.

Peas. Peas are grown under more or less similar climatic conditions as gram with the difference that they are generally irrigated in the plains. In the hills the crop is unirrigated. There are two types of peas, the garden or table peas and the field peas. In the North Indian plains, they are largely cultivated in U.P., Delhi and the Punjab on light sandy or loam soils. In the hills the crop is grown on acid soils. Manurial practices vary considerably in different States. The farmers generally apply farmyard manure directly to the peas or to the previous crop in the rotation. The use of fertilizers is still not widespread. The crop responds to fertilizers as well as to organic manures. The early experiments at Pusa (Bihar) justify the use of farmyard manure at 44.8 kg N|ha. The use of inorganic sources of nitrogen has not usually shown encouraging results. The application of phosphate at 67.2 kg P_2O_5|ha has been found to increase the yield of peas markedly. In the absence of organic manures, especially when the crop follows a soil-exhausting crop, the use of moderate dose of nitrogen will be desirable. Application of 20 kg N and 40 kg P_2O_5 is expected to be beneficial over a wide range of conditions, particularly because the crop is irrigated in the plains.

In areas where the soils are acidic as in Nilgiris and Manipur, application of lime to correct the soil acidity is necessary.

Khesari. *Khesari* is sown in standing rice and largely grown as *paira* or *utera* crop. It does not receive any fertilizer or manure directly. The low yield of the crop is partly due to poor physical condition of the soil at sowing because of no land preparation, defective crop stands and absence of manuring. It may be possible to improve its performance by applying an additional dose of phosphatic fertilizers to the rice crop as already mentioned, but experimental work on this aspect is lacking.

Black gram. Black gram (*Phaseolus mungo*) is grown without irrigation during the rainy season, either as a pure crop or in mixtures with other crops. In some of the States, where winter is mild and warm, the crop is grown in the *rabi* season on residual moisture or with irrigation. It is grown on a variety of soils but relatively heavy soil is preferred for its cultivation. The crop is either unmanured or inadequately manured with three to five tons of farmyard manure per acre. In some parts of the country woodashes are also applied in addition to farmyard manure. Experiments in Assam and elsewhere have shown that the crop responds to manuring. At Jorhat (Assam), dung at 44.8 kg N|ha increased the yield by 110 per cent, and oilcake at the same dose by 39 per cent only, but ammonium sulphate depressed the yield. This shows that the beneficial effect of dung is to be attributed to nutrients other than nitrogen. Substantial responses to farmyard manure and oilcake were also obtained on light sandy soils at Cuttack (Orissa), where application of ammonium sulphate also increased the yield.

Data on manuring of this crop are rather meagre for the formulation of a manurial schedule. A combination of a moderate dose of farmyard manure at five tonnes with 20 kg P_2O_5/ha may, however, be applied with advantage, if careful attention is paid to drainage of land in the case of the crop grown during the rainy season which is subject to conditions of excess water. If the crop is raised on residual moisture after rice, it would be desirable to give additional dose of phosphate at the time of sowing or transplanting of rice. The irrigated crop is expected to respond to fertilizer use, particularly phosphate.

Control of insect pests and diseases is of importance in assuring good response to manuring.

Green gram. Green gram (*Phaseolus mungo*) is grown under more or less similar conditions as black gram. As is true to other pulse crops, manuring of green gram also is very much neglected. In Peninsular India, the usual practice is to apply two to five tonnes of farmyard manure or compost per hectare as basal dressing in case of uplands. In lowlands, no manuring is practised. It is reported that Mung T. 1 responded to 33.6 kg N/ha in U.P. However, ordinarily application of nitrogen to this crop will not be required. The results of the Simple Fertilizer Trials in Andhra Pradesh and Orissa have shown that the yield of green gram was almost doubled through the application of P_2O_5 at 67.2 kg/ha.

The crop responds to liming on acid soils. Careful attention should be paid to drainage in the case of crop grown in rainy season, and to control of insect pests and diseases for obtaining good fertilizer response.

Arhar. *Arhar* or *tur* is largely sown mixed with *kharif* crops, such as *jowar*, *bajra*, rice and *ragi*, but is also grown as a pure crop in parts of U.P., Bihar, Madhya Pradesh and Rajasthan. It is often grown on borders of cotton and sugarcane. Data on manurial requirements of the crop are lacking. In general, 10 kg N and 40 kg P_2O_5 per hectare may be drilled at the time of sowing in pure crops and in cases where *arhar* and the principal crop with which it is mixed are sown in separate rows. As it is difficult to meet the individual fertilizer requirements of the pulse and non-legumes when they are growing intermingled in the field at random rather than in individual rows, it would appear to be more appropriate to grow them in individual rows from the point of view of manuring.

Arhar is susceptible to wilt which affects crop stand and response to manuring.

GROUNDNUT

About 97 per cent of the area under groundnut is rainfed. The rainfed crop is grown in parts generally receiving more than 51 cm rainfall. In parts of Tamil Nadu (specially South Arcot, Tanjore and Madurai), Andhra Pradesh, Mysore and Maharashtra the crop is raised under irrigation during summer. The crop is grown on red loams of varying texture and depth in coastal districts of Madras, western districts of Andhra Pradesh and most parts of Mysore; on black soils of ceded districts of Andhra Pradesh, Maharashtra, Gujarat and Madhya Pradesh; on gravel soils in parts of Salem and North Arcot districts of Madras, and in Chittoor, Anantapur, Kurnool and Hyderabad districts of Andhra Pradesh; and on sandy foams or light sandy soils in parts of U.P. and the Punjab.

Groundnut is grown both as a pure crop and as a mixture with *cholam*, cotton, castor, red gram or *ragi*. The pure crop is grown in rotation with millets and cotton in some parts of the country. In some places it is rotated with tobacco and chillies.

Manurial practices. The crop is sometimes manured with small doses of farmyard manure, either directly or it receives the benefit of residual effect of organic manures applied to the other crops in the rotation. Only a small proportion of the area receives fertilizers, but there is a growing awareness of the need for the use of fertilizers for this crop.

Response to fertilizers. In areas, such as Chhota Nagpur and the Deccan Plateau, where the soils are acidic, liming will help in improving the yield of the crop by supplying the calcium requirements of the crop and improving the environment for the development of rhizobial bacteria. Recent field trials at Nileshwar show that slaked lime gave encouraging results. Being a legume, a good response to phosphatic fertilizers is to be expected. Besides, experiments under the Co-ordinated Scheme of Agronomic Experiments show that in groundnut nitrogenous fertilizers gave as much response as phosphates in spite of the crop being a legume. There were also substantial responses to the application of potassium. The results of 196 trials under the Co-ordinated Agronomic Experiments' Scheme are tabulated below.

EFFECT OF N, P AND K ON THE YIELD OF GROUNDNUT (Q/HA)

	Control	22.4 kg N/ha	22.4 kg P_2O_5/ha	22.5 kg N + 22.4 kg P_2O_5/ha
Without K ..	12.1	14.1	14.2	15.8
22.4 kg N/ha ..	13.7	14.7	15.4	17.8

Further experiments have shown that the response to nitrogen is progressive and proportionate to the size of nitrogenous dressing as the higher level of nitrogen (44.8 kg N/ha) was almost as effective as the lower dressing (22.4 kg N/ha) per unit of nitrogen.

Relative effectiveness of different sources of nutrients: Experiments under the Co-ordinated Agronomic Experiments' Scheme have shown that A/S/N was better than the other sources of nitrogen, viz., ammonium sulphate, urea and C.A.N., which gave almost similar performance.

Among the phosphatic fertilizers, superphosphate (single) appears to be the best, except on acidic soils where basic slag may be as effective as superphosphate. The data on the relative performance of different phosphatic fertilizers on this crop in India are, however, lacking. Recent experiments in the Punjab have shown that the beneficial effect of fertilizers, such as sulphate of ammonia, superphosphate (single) and potassium sulphate, may be ascribed at least in part to the sulphur content in such fertilizers, as this nutrient plays a vital role in the control of the yield of this crop.

Time and method of application of fertilizers: As the crop is largely grown under unirrigated conditions and is deep rooted, it would appear to be the best practice to apply not only the phosphate and potassium, but also the entire dose of nitrogen at the time of sowing. As regards the method of application, in black soils of Mysore, a mixture of 1 cwt of ammonium sulphate and superphosphate is reported to be drilled along with the seed. The same appears to be the practice in Saurashtra. But, under the scheme 'Placement of Fertilizers' at Dharwar, Mysore, the best method was fonud to be plough-sole method of placement, 13 cm deep before sowing. A large number of experiments on placement of fertilizers have not been carried out, but it would appear that in many places it would be adequate if the fertilizers are drilled and the seed dropped with hand in the resulting furrows followed by planking to cover the seed.

Under irrigated conditions and in high rainfall areas, about half of the total dose of nitrogen could be top-dressed especially where the soil is light and the variety is a long-duration one and of spreading type. Top-dressing obviates the risk of leaching of the nitrogen.

Other factors influencing response to fertilizers:

MOISTURE SUPPLY: It has been experimentally found that the responses to N, P and K with irrigation are about 50 per cent higher than those under unirrigated conditions. This is to be expected as irrigation affords control over the moisture supply on which fertilizer response depends.

SOIL TYPE: The response to N, P and K on major soil type did not vary much among themselves.

CULTURAL PRACTICES: The poor stands (low plant population) of groundnut generally lower the yield of this crop in many areas. The low plant population may also result in lowering the response to fertilizer use. The practices which improve the germination and stand of the crop will, therefore, help in making the most efficient use of the fertilizer applied. Plant protection measures would also help in minimizing the incidence of insect pests and diseases, and in favouring the response to fertilizer applications.

CASTOR

Castor is generally grown as a rainfed crop though it responds to irrigation. It is grown as a pure or mixed crop on relatively poor soil (sandy or red soils and rice fallows). As a mixed crop it will share the manuring of the principal crop, such as *jowar*, *bajra*, cotton and groundnut, in the mixture.

Although it has low nutrient requirement, application of 15–30 kg N, 40–60 kg P_2O_5 and 40–60 kg K_2O per hectare would help to ensure high yield and maintain soil fertility because the crop is grown on poor soil. The fertilizer may be drilled at plough-sole depth and castor sown in the resulting furrows.

SESAMUM

It is grown as a rainfed crop in North India, but as a *kharif* as well as a *rabi* crop in the southern and the eastern States. The crop raised in the *rabi* season is generally irrigated. It is grown either as a pure crop or is mixed with other crops. When sown mixed, it shares the manuring of the principal crops with which it is grown. When grown as a pure crop the crop hardly receives any manuring or fertilizers. There are also no experimental data on the response of the crop to manuring; however, 15–20 kg per hectare of nitrogen applied at sowing is expected to increase the yield.

If the seed-bed is sufficiently moist at the time of sowing, as is the case when the crop is sown after a pre-sowing irrigation, the fertilizer may be drilled and seed dropped in the resulting shallow furrow of 2.5–3.75 cm deep. The same practice could be adopted when the crop is sown in the *kharif* after rainfall. Direct contact between the seed and the fertilizer must be avoided as the germination may be impaired. When the seed is broadcast the fertilizer may also be broadcast in the case of *kharif* crop. In the *rabi* crop it would be desirable to drill the fertilizer and seed separately.

LINSEED

Linseed is grown as a winter crop in India in more or less similar climatic conditions as for wheat and gram. The crop is grown without irrigation on heavy and deep black cotton soils, retentive of moisture in Madhya Pradesh, Maharashtra, Rajasthan and Mysore States and as an irrigated or unirrigated crop on alluvial soils in U.P., Bihar and West Bengal. It is also raised as *utera* or *paira* in paddy fields. It is commonly grown as a mixture with gram, wheat or barley.

The crop is rarely manured with organics or inorganics in practice. However, it responds well to nitrogenous fertilizers in most places. The use of phosphatic fertilizers is also expected to be beneficial, provided the fertilizer is placed in the deep moist layer of the soil. Very little work, if any, has been done on the manuring of this crop in India.

Fertilizer practices

Irrigated conditions: If a pre-sowing irrigation is applied and seed-bed is moist, the fertilizer should be drilled after seed-bed preparation with a plough having a narrow body and the seed dropped in the resulting shallow furrows of about 3.75–5 cm depth. When a pre-sowing irrigation is not applied conditions at sowing under irrigation and unirrigated conditions will be similar. The fertilizer should be drilled deep to lie in moist layer. The *paira* or the *utera* crop cannot be directly manured conveniently and considerable experimental work is needed before a sound fertilizer practice could be recommended for such a crop. However, *paira* crop could benefit from the residual effect of phosphate applied to paddy at sowing or transplanting and from the nitrogen applied to paddy as a top-dressing. The preceding rice crop should, therefore, invariably be well-manured whenever a *paira* or *utera* crop is to be taken.

Conditions conducive to fertilizer response: Linseed has low irrigation requirements and is generally grown on relatively heavier soils having good moisture-retaining capacity. Wherever irrigation facilities are available, it would be desirable to irrigate the crop and obtain high yields through application of high doses of fertilizers. Under unirrigated conditions, the fertilizer doses have perforce to be kept low. Similarly, timely sowing and close spacing of plants are expected to lead to higher fertilizer response than later sowing of crop with sparse stand.

RAPE AND MUSTARD

Rape and mustard are generally grown mixed with other crops, such as wheat, gram and barley, under unirrigated conditions. However, *toria* is generally grown as a pure crop under irrigation in the Punjab and under unirrigated conditions in U.P. Brown *sarson* is also grown pure under unirrigated conditions in the Punjab and U.P. In the Punjab, *toria* follows *kharif* fallow and generally receives no manures. Progressive growers in U.P., green manure the field to be cropped with *toria*. In U.P. brown *sarson* often receives 10.16–15.24 tonnes of farmyard manure per hectare a month or so before sowing.

Toria profits from application of nitrogenous fertilizers at 20–25 kg per hectare. Brown *sarson* and *rai* also respond well to N at 30 kg per hectare. Response to phosphate is not consistent, but a dressing of about 25 kg P_2O_5 per hectare may be useful in some areas. The fertilizer should be drilled irrespective of whether the seed is sown by broadcast or drilling method. The seed and the fertilizer should not be drilled together as this is likely to impair germination and affect the crop stand.

COTTON

About 87 per cent of the area under cotton in India is irrigated. American cotton (*G. hirsutum*) is exclusively grown under irrigation on the Indo-Gangetic alluvium, and Cambodia (*G. hirsutum*) cotton on red soils in Coimbatore and Salem districts. *G. arboreum* is irrigated to a small extent only in North India and is largely a rainfed crop. Bulk of the area under *G. arboreum* and *G. herbaceum* lies in Central and Peninsular India and has heavy black soil. *G. herbaceum* is also grown on coastal alluvium in parts of Gujarat and Mysore States.

The soils on which cotton is grown have neutral or alkaline reaction, except in some parts where it is grown on red soils.

Cotton follows *toria*, gram, wheat, *guar* and *jowar* in North India. In Madhya Pradesh, Mysore and Maharashtra, cotton follows *jowar*, or wheat, or groundnut. In Mysore, *ragi* is grown in rotation with cotton. On light soils, *bajra* or sesamum takes the place of *jowar*.

In recent years, *rabi* cotton has assumed some importance in rice fallows in Andhra Pradesh.

Cotton is grown as pure crop and sometimes as mixed crop with maize, *jowar*, pulses, vegetables, castor and groundnut.

Manurial practices adopted by farmers. A very small portion of the unirrigated crop receives any manure. According to a survey conducted in Madhya Pradesh, only 22 per cent of the area was manured with farmyard manure or compost. Irrigated crop is often manured with farmyard manure, but till recently use of fertilizers has been low for this crop.

Kinds of fertilizers. It has been found that manuring with nitrogenous manures or fertilizers is the principal need of the crop except in parts of Gujarat and Madras, where favourable responses to phosphate have been recorded. It appears deep-rooting habit of cotton helps it to meet most of its requirements of P and K from larger soil volume. Application of phosphate to a legume, such as groundnut, *guar*, pea, gram, in the rotation normally leaves enough residual effect to obviate the need of any phosphate to cotton, except in cases of acute phosphate deficiency.

Sea Island cotton grown on a small scale in Mysore and Kerala has been found to respond to all the three nutrients, N, P and K.

The crop, generally grown on soils of neutral to alkaline reaction, does not require any liming but on acid soil in Chhota Nagpur, liming is reported to have given encouraging results.

In the experiments conducted in the past, application of 22.4 kg N/ha under rainfed conditions gave economic returns. Under irrigated conditions doses as high as 112 kg N/ha proved optimum at Abohar (Punjab). In Gujarat, 44.8 kg N and 22.4 kg P_2O_5 are suggested under irrigated conditions and half the amount of nitrogen under unirrigated conditions. Dose of N to be applied would in practice depend on the previous crop as well. Where crop is grown after a legume the dose of nitrogen could be reduced. High doses of fertilizers would be needed in the case of cotton grown in rice fallows or when cotton follows a soil-exhausting crop, such as *jowar*, wheat and *ragi*, under irrigation. The belief that farmyard manure or compost must be used in conjunction with fertilizers is not well founded. It would be more appropriate if available farmyard manure is applied to cereals grown in rotation with cotton rather than applying it to cotton in combination with fertilizers or oilcakes.

Forms of nitrogen: Nitrogenous fertilizers and oilcakes are good sources of nitrogen. Under rainfed conditions, groundnut cake has been found to be particularly effective as it releases its nitrogen gradually for crop use. However, because of the value of edible oilcakes for cattle feed and their higher cost per unit of N than nitrogenous fertilizers, the latter can gainfully substitute oilcakes.

Among nitrogenous fertilizers, Chilean nitrate has given slightly better results than ammonium sulphate in some of the experiments. Any of the available sources, ammonium sulphate, calcium ammonium nitrate, A|S|N could be used by paying attention to time and method of application.

Time of application: Phosphate and potassium, when needed as in the case of Sea Island cotton and phosphate in Gujarat on red soil in Madras, should invariably be given at|or before the sowing of cotton. The same applies to N when oilcake is used as source of nitrogen. For other sources of nitrogen, time of application would depend on the type of cotton grown. In rainfed *arboreum* cotton on black soil an application at sowing would appear to be the best. As sowing under rainfed conditions have to be completed in a short period, application of fertilizers, a few days in advance to sowing with seed-bed preparation following pre-monsoon showers, would be more practicable than that at sowing. In longer duration varieties (*herbaceum* cotton) application at six weeks after sowing has been found to give better results than earlier application in Gujarat. For irrigated American cotton in the Punjab, a split application, one-half at thinning and one-half at commencement of flowering, was more effective in yield than earlier application at sowing which stimulated vegetative growth to a greater extent than the later application.

Method of application: Phosphatic fertilizers (when used) and oilcakes should invariably be drilled. Nitrogenous fertilizers would also give better results if drilled, especially in separate rows, a few centimetres away from the seed row, and may otherwise be broadcast. In no case any of the fertilizers are to be mixed with seed at sowing as the combined drilling might impair the germination and reduce the stand of the crop. When a part or the whole of the nitrogen is top-dressed, it should be applied along the cotton rows, followed by a good irrigation immediately. Heavy doses of nitrogen applied along the rows, particularly when the plants are young, may cause damage to seedlings, if light rain follows fertilizer application and irrigation is withheld.

Conditions influencing fertilizer response. Soil and climatic conditions influence fertilizer response in cotton. Moisture deficiency or excess of moisture occurring alone or intermittently limit yield and fertilizer response under rainfed conditions. Excess moisture during flowering turns the plant to vegetative activity and excessive flower and boll shedding, resulting in reduce effectiveness of fertilizers under irrigated conditions too, in areas subject to high rainfall in the monsoon season. Both moisture conservation and drainage are important under unirrigated conditions in some places, subject to intermittent drought and flooding during the rainy season, because of the variations in the distribution of rain.

Black soil is particularly subject to excess moisture in places, such as Malwa region, necessitating drainage. For moisture conservation in low rainfall areas, the sub-division of fields into check basins or basin-listing is expected to be helpful. Restricting the cultivation of cotton to high-lying fields and adoption of graded border strips or contour furrows are necessary in areas of excess rainfall, whether under irrigated or unirrigated conditions, to facilitate drainage. Success of this crop in new irrigated areas receiving good *kharif* rain depends on careful attention being paid to drainage. Salinity and|or alkali conditions in the subsoil is another factor which has been found to inhibit the response of cotton to nitrogen in the Punjab.

Under irrigated conditions more frequent irrigations at flowering and fruiting in the absence of rainfall improves fertilizer response.

Timely sowing is conducive to the highest fertilizer response. Earlier sowing generally gives higher response. In later sowing, the response can be improved to some extent by closer spacing of plants. The low response to rainfed cotton is partly due to the fact that sowing is perforce delayed. Transplanting of cotton seedlings grown in polythene bags or leaf cups, which has given encouraging results in preliminary trials may help to solve the problem.

As nitrogen application increases the insect attack, adoption of plant-protection measure will help in increasing the fertilizer response.

The improved methods of cultivation adopted at Amravati (Maharashtra) have revealed that with careful preparatory tillage, seed dressing with Agrosan before sowing, hand-weedings and hoeing for intercultivation, treatment with insecticides for control of common insect pests, and applying farmyard manure at the rate of 25 cartloads per hectare and application of 22.4 kg N, 44.8 kg P_2O_5 and 44.8 kg K_2O|ha at sowing time with a top-dressing of 22.4 kg N|ha at the time of flowering gave a yield of 1,244 kg of *kapas* per hectare as compared with 463 kg of *kapas* obtained from traditional practices. The net profit obtained with the adoption of these practices was Rs 503 per hectare.

JUTE

Jute is mainly grown on soils of alluvial region in Assam, West Bengal, Orissa, Bihar and *terai* region of U.P. Inundated lands near river banks are very suitable for jute cultivation. The soils are generally acidic, except the calcareous belt of north Bihar which is alkaline in reaction. Two cultivated species, *C. capsularis* and *C. olitorius*, are grown. In high-lying fields the land is cropped with late varieties of jute and is followed by potatoes or pulses. Jute is also grown in rotation with rice.

Manurial practices vary considerably in different areas. When grown in rotation with potatoes as in Hooghly and the 24-Parganas, the residual effect of the high doses of manures and fertilizers applied to potatoes is sufficient to obviate the need of any direct manuring of jute crop. In other cases manuring practice consists in the application of cowdung at two to four tons per acre during land preparation. Water-hyacinth and silt from ponds and tanks are used wherever available. The use of fertilizers has not been widespread and deserves consideration for increasing the yield of this crop in India. In China, where jute yields are much higher than in India, nightsoil and fertilizers are reportedly used to supply 103.13 kg N, 146.85 kg P and 325.2 kg per ha.

As the crop is largely grown on acidic soil, application of lime is found to be beneficial in such soils. Experiments at the Jute Agricultural Research Institute have shown that top-dressing with nitrogenous fertilizers at 22.4 kg N|ha increases the yield of fibre by 238.5 kg|ha in *C. olitorius*. *C. capsularis* requires 44.8 kg N or a still higher dose. In an experiment at the Institute, 'JRC-212' gave the best yield with 67.2 kg N whereas the other varieties, 'D. 154', local and 'JRC-321', gave as good yield with 44.8 kg N as with 67.2 kg N|ha. Top-dressing is advocated because earlier application at sowing may lead to loss in two ways, i.e., through leaching and through removal of nutrients by plants which are thinned out.

Experiments have shown that different sources of nitrogen are almost equally effective in jute. The application of phosphate and potassium has not generally increased the yield of fibre. Phosphate application may, however, prevent lodging of plants on light soils by promoting root development and may be worthwhile when used in combination with high dose of nitrogen. Addition of potassium may usefully check the diseases and counteract the adverse effect of excess of nitrogen. Simple Fertilizer Trials on Cultivators' Field in West Bengal have shown substantial response to potassium on the Ganga flat land and on red soil.

When grown in rotation with potato, which receives heavy dose of organic manures and fertilizers, no fertilizer need be applied as is the general practice.

SUGARCANE

About 70 per cent of the sugarcane grown in India is irrigated. It is grown mainly without irrigation in Bihar, Assam and West Bengal. The soils are of varying texture, ranging between heavy black soils of Bombay (Deccan) and sandy loam alluvial soils in northern India. Fine-textured soils are usually preferred as they are more retentive of soil moisture. The soil reaction of sugarcane soils ranges between acidic in Assam and alkaline in parts of U.P. and the Punjab. The cultural and manurial standards are much higher in the cultivation of sugarcane in Peninsular India than those in North India. These, apart from the favourable climatic factors, are responsible for relatively much higher yields of sugarcane in Peninsular India.

The crop is largely manured with farmyard manure in many parts of North India. Nitrogenous fertilizers are becoming popular, but the crop hardly receives any phosphatic and potassic fertilizers. The fertilizers are used on a fairly large scale in Maharashtra and in the southern States.

Response to fertilizers. Experiments conducted at the Government Research Stations and in Simple Fertilizer Trials on Cultivators' Fields have shown universal response to nitrogen. The increase in yield from 67.2 kg N per hectare was 25, 27 and 28 per cent over the control in western, eastern and *terai* regions. When the dose of nitrogen was doubled the increase in yield was 51–59 per cent over the control. The Simple Fertilizer Trials were conducted on different soil types in a number of States. The results obtained are tabulated on page 323.

As Indian soils are generally deficient in nitrogen, nitrogen application influences tillering, leaf growth and consequently the weight of canes. Excess of nitrogen has, however, to be avoided as it adversely affects the quality of juice by reducing sucrose percentage and by increasing glucose. Excess of nitrogen also induces lodging of cane with its resultant ill-effects. The dose of nitrogen to be applied will vary from State to State and in the different areas within the States. In North India, where growing season is relatively short, application of nitrogen between 672–112.1 kg N|ha is adequate. In the southern States of Tamil Nadu, Mysore and Andhra Pradesh, the dose of N varies from 224.2–336.3 kg per hectare in the absence of green manuring. In Maharashtra doses higher than these are being used. In the case of *adsali* crop of 18–20-month duration, the dose of nitrogen is as high as 504 kg|ha.

RESPONSE OF SUGARCANE IN (TONNE/HA) TO N, P AND K IN DIFFERENT SOILS OF INDIA

Soil class	No. of trials conducted	Average yield of untreated plots	Response to		
			N at 67.2 kg/ha	P_2O_5 at 44.8 kg/ha	K_2O at 44.8 kg/ha
	North India				
Alluvial	472	44.0	11.2	5.9	3.9
Hilly	45	33.9	13.9	6.5	4.0
Terai and submontane	102	42.6	14.3	7.4	3.4
	South India				
			N at 186.1 kg/ha	P_2O_5 at 89.6 kg/ha	K_2O at 9.68 kg/ha
Coastal alluvium ..	59	60.2	7.9	6.0	11.3
Red and black ..	45	77.3	10.0	4.9	6.6

Among the different sources of nitrogen, viz., ammonium sulphate, urea, ammonium sulphate-nitrate, calcium ammonium nitrate, the new fertilizers are as good as (and sometimes better than) ammonium sulphate. The locally-available fertilizers should, therefore, be used.

In the experiments under the Simple Fertilizer Trials on Cultivators' Fields, substantial responses to phosphate and potassium have been obtained, both in North India and in South India, irrespective of the type of soil. It also stands to reason that with the increasing use of nitrogenous fertilizers, the need for phosphatic and potassic fertilizers will be obvious. In view of this, application of phosphate at about 33.6–84.0 kg is recommended in many of the States of Central India. Still higher dose up to about 112.1 kg P_2O_5 is advocated in Maharashtra and Mysore. Application of potassium also forms a part of the recommended schedule in some of the States. In Bihar it has been noted that some of the areas show distinct response to potassium.

Time and method of application. The entire doses of phosphatic and potassic fertilizers should be applied at the time of planting. The fertilizers may be applied in furrows just before planting the sugarcane setts. Nitrogen application should be split. About 33.6–67.2 kg N/ha may be applied in furrows and the rest should be top-dressed in one or two instalments. The first top-dressing may be given about six to eight weeks after planting and the next before earthing up. It is important that the top-dressing is not unduly delayed as late application would tend to produce ineffective tillers which will not be carried to maturity.

Conditions favouring fertilizer response. A good germination and optimum stand of the crop are important to obtain the best returns from the fertilizers. Use of selected seed and control of white ants is also important. The crop should be irrigated frequently so that it does not experience a stress at any of the stages throughout its growth. As the crop can be grown in rows, frequent intercultures will help in controlling the weeds. Useful weedicides have also been developed which can help in the control of weeds not only in the inter-row spaces, but also the weeds growing in the rows which cannot be controlled by cultural methods. In some areas, the yield of cane and the quality of juice is liable to be affected by conditions of excess water and salinity. Although sugarcane is somewhat tolerant to water-logging and salinity, these conditions are not conducive to the best yield of sugarcane. Therefore, proper drainage for the removal of excess water may be provided.

Green manuring. Green manuring helps in improving the yield of sugarcane and is advisable where conditions permit. Since growing of the green-manure crop in advance involves the loss of a crop season and sugarcane can be grown in widely spaced rows, it is possible to intercrop sugarcane with a suitable legume and turn under the green material at the time of earthing up. There is also evidence to show that much of the beneficial effect of a green-manure crop grown in advance can still be obtained if the shoot portion of the green-manure crop is used as fodder. The beneficial effect of the organic matter content in the roots of the countries very heavy yields of sugarcane have been obtained with the use of fertilizers alone, without the addition of any organic manures.

POTATO

Potato is grown on normal soils, almost wholly under irrigation in autumn or winter in the plains and on acid or acidic soil under rainfed conditions in summer in the hills. In the Nilgiri Hills (South India), two rainfed crops, in addition to an irrigated crop on small areas, are raised during the year. In Chota Nagpur Plateau (Bihar) and areas with similar climatic conditions elsewhere, a monsoon crop is taken on red sandy or acidic soil on a small scale.

Light sandy or sandy loam soils are preferred for the cultivation of potato. For early crops in the plains, well-drained, light soils are an essential pre-requisite. The potato is generally included in high-intensity rotations, mostly follows a soil-exhausting crop, and is manured invariably.

Most of the farmers apply heavy doses of farmyard manure alone or in combination with oilcakes. In some places oilcakes are applied 2,755–3,673 kg/ha. However, in Patna city area where potato is grown on heavy soil inundated during the monsoon season, neither farmyard manure nor oilcake is applied but a nitrogenous fertilizer is invariably applied. Although the use of nitrogenous fertilizers is becoming increasingly popular, superphosphate and potassic fertilizers are not used to any appreciable extent, except in the Nilgiris, where the fertilizer schedule recommended by the State Department of Agriculture is being used extensively.

Bulky organic manure. If available, 25.40 tonnes per hectare of farmyard manure or dung or compost may be applied three to four weeks before planting and incorporated in the soil. In case potato follows maize which also responds well to farmyard manure, the application of the manure could be made to the maize crop.

Where farmyard manure is not available, green manuring with sannhemp or *dhaincha*, depending on conditions, particularly on light sandy soils, would be desirable. However, green manuring involves loss of a crop, and may not be an attractive proposition to a small holder practising intensive system of cropping. The alternative is to grow legume but remove it as fodder.

Nitrogenous manures and fertilizers. Nitrogen is the most important nutrient required for potato. Its deficiency is reflected in pale-green appearance, premature yellowing of leaves, and stunted growth of plants. Its application results in vigorous plants with dark-green and well-expanded leaves, and more tubers of large size. Response to nitrogen is obtained on all soils, both in the presence and the absence of farmyard manure. Nitrogen may be supplied in the form of oilcake or a nitrogenous fertilizer, singly or in combination. Of the two, the fertilizer is the cheaper source of N.

In the experiments at Central Potato Research Institute, average increase in yield of potatoes was 4,224 and 5,786 kg to application of 275–551 kg of sulphate of ammonia per ha respectively. The response to 918 kg of oilcake was 2,663 kg of potatoes per ha. The effect of oilcake and sulphate of ammonia in combination was less than the sum of their responses in isolation. Nitrogenous fertilizers can, therefore, replace the oilcake almost wholly.

Early crops or late crops may be given 60–90 kg N/ha. The same applies to main crops in areas of short and mild winter. For main crops in areas of long winter 90–150 kg N/ha is advisable. Nitrogenous fertilizer should be used, even if farmyard manure has been applied as a basal dressing at about 25.40 tonnes per hectare. The actual dose to be applied within the range will depend on previous crop, date of planting, moisture supply, etc.

With respect to the effect of the different nitrogenous fertilizers, it may be generalized that sulphate of ammonia has given the best performance. Urea and ammonium nitrate are also good sources of nitrogen. Chilean nitrate is generally less effective than sulphate of ammonia. Ammonium chloride cannot be considered as ideal N-carrier for potato because of its chloride content which is known to adversely affect the dry matter content and the quality of potato.

Studies on the time of application have shown that early application at planting and split application, where a part of the dose is applied at planting and the rest at earthing up time, were better than late application at earthing up. The best practice would, therefore, be to apply sulphate of ammonia (or other available nitrogenous fertilizer) in furrows at planting just below the seed tubers, if the rate of application is up to 80 kg N/ha. With higher doses the entire quantity may be broadcast and incorporated with the soil by ploughing a day or so before planting of potatoes; alternatively, dose up to 80 kg N/ha should be applied in furrows at planting and the rest top-dressed just before the digging operation which precedes earthing up.

To achieve the best results from nitrogenous fertilizers optimum levels of planting date, soil tilth and moisture supply should be ensured. Too early plantings, when soil and atmospheric temperatures are high, and also delayed plantings which curtail the growing season reduce the response to fertilizers. The first fortnight of October in areas subject to early frost and the last week of October to first week of November in frost-free areas, may be considered as optimum for main crops. Frequent irrigation to keep the soil moist are conducive to the best fertilizer response.

Phosphatic fertilizers. Deficiency of phosphate is characterized by erect and stunted plants with staring habit having dull green leaves, closely spaced internodes and small-sized leaflets. In contrast, good phosphate supply is indicated by tall plants with free-branching habit having bright green, fully expanded leaves and leaflets. Phosphate application helps in good root development, large number of tubers and early bulking. They are, therefore, specially valuable for seed crop, for early crops and late crops, and to obtain sizable crops, in spite of early lifting necessitated in these cases.

Majority of potato-growing soils are deficient in phosphate. Application of phosphate at 60–90 kg P_2O_5/ha is expected to be profitable over a wide range of conditions in the absence of farmyard manure and about 40–60 kg/ha if a basal-dressing of farmyard manure at about 25.40 tonnes per hectare is applied.

Experiments at the Central Potato Research Institute have shown that, of the phosphatic fertilizers, superphosphate (single) gave slightly better performance than bone-meal. Rock phosphate was not effective in the plains because the soil reaction is nearly neutral or alkaline.

The phosphatic fertilizer should be applied (in combination with potassium) in furrows just before planting seed potatoes, but never broadcast. Alternatively, a part of the phosphate may be applied to the preceding legume, green manured or removed as fodder. In the latter case, not only is the yield of legume fodder increased but also sufficient residual effect left for the use of potatoes.

In heavily levelled areas, acute deficiency of phosphate is likely to occur. In such cases heavy doses of phosphate must be applied directly or preferably to the preceding green-manuring crop.

Potassic fertilizers. Potassium is removed by this crop in larger quantities than nitrogen and phosphorus. It balances the effect of excess of nitrogen and phosphate, and reduces the incidence of leaf-spot diseases and frost injury.

In the Western potato-growing countries, the crop enjoys priority in the allocation of supplies of potassic fertilizers. On the other hand, the crop in the plains of India seldom receives any potassic fertilizers. In the experiments conducted by the Central Potato Research Institute responses to potassic fertilizers were obtained in about 33 per cent of the cases. The inconsistent responses to the important nutrient calls for consideration of factors and conditions which govern the response to this nutrient. These factors are: (*a*) soil type, (*b*) application of farmyard manure, (*c*) differential response of potato varieties, and (*d*) time of lifting. Experiments have shown that intensively cultivated, light sandy soils and lateritic soils respond to potassic fertilizers.

Application of heavy doses of farmyard manure, compost or dung which contain substantial amounts of potassium may correct the ordinary deficiency of potassium to a large extent, but application of the low dose of potassic fertilizer will still be desirable if dressing of farmyard manure are modest or when deficiency of potassium is acute.

Varieties differ in the severity of deficiency symptoms exhibited by them and the response to potassic fertilizers. At Patna, local varieties (*Phulwa* and Darjeeling Red Round) showed mild symptoms such as bluish-green leaves. Up-to-date, Craig's Defiance and Furore exhibited bronzing on the leaf surface and gradually developed dark-brown necrotic spots, marginal leaf scorch and premature dying of leaves. Hybrid O.N. 2253 showed yellowing of leaves. Response to potassic fertilizer was most pronounced in the foreign varieties (Up-to-date, Craig's Defiance and Furore), less so in O.N. 2253 and D.R.R. and the least in *Phulwa*. Varieties which bulk rapidly and produce large-sized tubers eventually showed severe deficiency symptoms without potassium and responded most to potassic fertilization.

As potassium deficiency appears in later stages and reduces the size of tubers, it would be normally expected that potassic requirements of the early and the late potatoes would generally be lower than that of the main crop, variety remaining the same. Since variety Up-to-date can be grown as early, late and main crops, this would appear to be the case. However, main crops are largely grown with *Phulwa* and D.R.R., and the early crops and late crops are grown with varieties of early bulking habit. In the plains the early and late crops are also subject to leaf-spot diseases, such as early blight and *Cercospora,* from which the main crop generally escapes. Application of modest dose of potassic fertilizer in practice would, therefore, be important for early and late crops too.

Briefly stated, application of about 100–150 kg of K_2O/ha may be applied to varieties, such as 'Up-to-date', grown as main crop on light sandy or red laterite soil in the absence of farmyard manure. The dose may be reduced to half when farmyard manure at about 25.40 tonnes/ha is used, or when local varieties are used or when a variety, such as Up-to-date, is used as early or late crop instead of as main crop. The potassic fertilizer should be mixed with the full dose of superphosphate (single) and a moderate dose of nitrogen for application in furrows just before planting in furrows or on low ridges. Of the two kinds of potassic fertilizers, potassium sulphate is preferable to muriate of potash, as chloride content of the muriate is not considered to be suitable for potato.

Manuring of potatoes in the hills. As the crop is grown under unirrigated conditions the responses of fertilizers will depend on the amount and the distribution of rainfall. Fertilizer use will, however, still be necessary to obtain good yields. Because of the variable responses smaller doses of manures and fertilizers may be applied. Application of farmyard manure at 15 tonnes/ha, N at 60 kg/ha and P_2O_5 at 60 kg/ha may be generally recommended for the hills. Application of 30 kg K_2O per hectare in the presence of farmyard manure and 60 kg per hectare in its absence will be desirable. In areas of assured rainfall, the manurial doses could be increased by about 50 per cent. As the soils in hills are acidic, phosphatic fertilizers, such as bone-meal, could also partly replace superphosphate.

In the Nilgiris in South India, a manure mixture consisting of 250 kg of groundnut-cake, 90 kg of ammonium sulphate, 158 kg of bone-meal, 305 kg of superphosphate and 101.6 kg of potassium sulphate per 0.45 ha, to supply 38.5 kg nitrogen, 97 kg phosphoric acid and 50 kg potash per 0.45 hectare is recommended for potatoes by the Department of Agriculture, Madras.

Seed and other factors in relation to fertilizer use. Only healthy plants can utilize the nutrients supplied through fertilizers. Use of virus-free seed is, therefore, of utmost importance. Moreover, seed should not be infected with other seed-borne diseases, e.g., charcoal rot, bacterial wilt and brown rot, black scurf, etc. Pre-sprouting of seed increases fertilizer response, and is specially important for all potatoes. The sprouts should be short, sturdy and thick. If freshly harvested seed is used it should be treated with dormancy-breaking chemicals such as thio-urea. Late blight and other diseases and insect pests should be controlled to obtain the best results from manuring.

As potato is tolerant to soil acidity, the pH of soil is seldom so low as to need liming.

TOBACCO

Tobacco is a transplanted crop. The manurial requirements of the crop in the field differ with the kind of tobacco and the purpose for which it is grown. The requirement of seed-bed manuring, however, does not differ materially with the kind of tobacco. *N. tabaccum* is grown for cigarettes, cigar, *cheroot, bidi, hukka*, chewing and snuff purposes. *N. rustica* is grown for *hukka*, chewing and snuff purposes. The purposes for which tobacco is grown; areas in India and soil conditions are tabulated on page 330.

Purpose	Areas	Predominant soil conditions	Irrigated or not
Cigarette	Andhra Pradesh (Guntur, Krishna, East and West Godavari districts)	Heavy black soil	Unirrigated
Cigar *Cheroot* *Bidi*	Mysore	Sandy to sandy loam	Irrigated
	South Madras	Light gravelly to sandy loam	Irrigated
	Gujarat (Kaira and Baroda districts)	Light to medium clay loam	Irrigated in years of low rainfall
Hukka	Nipani Zone	Silt loam	
	Bihar, West Bengal	Sandy loam to loam	Irrigated once or twice
Chewing	U.P. and Punjab	—do—	Irrigated
	Almost all States, particularly Madras and Kerala	Gravelly to sandy loam	Irrigated

Besides the above, in Andhra Pradesh, two well-known types, *Lanka* and *Natu*, are also grown exclusively for making hand-rolled *cheroots*.

Flue-cured tobacco

Seed-bed manuring: Nurseries raised on sandy soils of Bapatla and Chirala (Andhra Pradesh) do not generally receive any farmyard manure. Ammonium sulphate at 16.8 kg/ha is applied soon after germination. Subsequently, 22.6–45.3 kg of the fertilizer are applied periodically according to the growth and vigour of the seedlings and the colour of the foliage. About 448–560 kg/ha of the fertilizer is used in all.

Recent experiments at the Central Tobacco Research Institute have shown that on heavy black soil of Andhra Pradesh, application of 13.6 kg N combined with application of heavy dose of farmyard manure as a layer over the top surface was highly advantageous in producing early and larger number of healthy and vigorous transplants.

In the U.S.A., fertilizer mixtures are used in high doses in nursery beds. Applications of as high as 0.227–0.908 kg per 0.859 m^2 of 4-9-3 mixtures are applied to cigarette tobacco nursery beds.

Manuring the field. The crop has low nitrogen requirements. Excess of nitrogen must be avoided as it spoils the quality of leaf as indicated by the reduction of bright grades of cured leaf. Some growers of flue-cured tobacco apply *three to five tons* of farmyard manure per acre supplemented by groundnut cake. In Andhra Pradesh, many farmers apply 112–224 kg of fertilizer mixture supplying + 11.2–22.4 kg N, 56–84 kg P_2O_5 and 13.4–40.2 kg K_2O per hectare.

Experiments conducted by the Central Tobacco Research Institute over a number of years show the relationship between nitrogen and initial fertility status of the soil and rain received after fertilizer application. In seasons when there was rain after fertilizer application, the response to nitrogen fertilization was evident. Application of 22.4 kg N per hectare at Rajahmundry was generally economical, but not at Guntur. Earlier experiments at Guntur, however, did show substantial response to nitrogen. Although direct response to nitrogen depends upon the rainfall after fertilizer application there is evidence to show that nitrogen application even in low doses leaves substantial residual effect on the following crop of tobacco.

Experiments at Guntur and Rajahmundry over a number of years have not shown any favourable response to applications of phosphatic and potassic fertilizers. There is, however, some indication that phosphate application at 13 to 15 cm depth helps in improving the proportion of bright grades of tobacco. In Mysore, 6,530–12,550 kg of farmyard manure, about 56 kg ammonium sulphate, 168 kg superphosphate and 33.6–74 kg potassium sulphate per hectare are applied. The inconsistent response to nitrogenous fertilizers and the absence of responses to phosphate and potassium on heavy black soil may be partly ascribed to the fact that the crop is wholly grown under unirrigated conditions, after the cessation of the monsoon rains. Fertilizers applied, at or near planting, therefore, remain in the dry soil layer (even when they are applied in the furrow at 5–7.5 cm depth). The application by broadcast method would be still less effective (the practice which is quite common with the growers). Recent placement experiments at the Central Tobacco Research Institute suggest the possibility of improving the yield and the quality of cigarette tobacco by proper fertilizer placement, improving the physical conditions of soil, and soil moisture conservation through mulching.

Cigar and chewing tobacco

Seed-bed manuring: The seed-beds are commonly manured with 25,100–75,300 kg farmyard manure per hectare. Experiments at the Cigar and Cheroot Tobacco Research Station, Vedasandur, suggest that 18,193 kg seived farmyard manure, 90.7 kg ammonium sulphate, 181.9 kg superphosphate and 90.7 kg sulphate of potash would form good basal dressing.

Manuring of the crop in the field: Cigar and chewing tobacco require heavy manuring and are normally manured with 37,650–50,200 kg of farmyard manure per hectare applied a month before transplanting. In some cases, sheep and goat folding is done but fertilizers are not generally used.

Although heavy application of organic manure is conducive to high yield consistent with good leaf quality, there is considerable scope for supplementing farmyard manure with inorganic nitrogenous fertilizers or partially replacing the dose of farmyard manure by nitrogenous fertilizers. Studies at Cigar and Cherrot Tobacco Research Station, Vedasandur, revealed that the optimum combination was farmyard manure at ten tonnes supplemented with 112 kg of nitrogen per hectare irrespective of the source of the fertilizer. Higher doses of farmyard manure increase costs without commensurate returns in yield.

Potassium is an important fertilizer element for cigar tobacco as it influences the physical quality of leaf and the smoking quality. In the U.S.A. and Canada, 134.9–224 kg K_2O per hectare are generally applied. However, experiments at the Cigar and Cheroot Tobacco Research Station, Vedasandur, did not show any favourable response to potassic fertilizers.

Phosphate is required in low quantities 9–18 kg P_2O_5, but is invariably applied in other countries at the rate of about 89.6 P_2O_5 per hectare. On the other hand, experiments at Vedasandur have not justified the application of phosphate from any of its carriers, i.e., superphosphate, bone-meal or rock-phosphate. The absence of response to phosphate and potassium may be due to one or more of the following three causes: (a) the presence of adequate quantity of these nutrients in the soil, (b) calcareous nature of the soil which limits the absorption of potassium, and (c) application of farmyard manure in high doses which supplies considerable quantities of P and K.

All the sources of nitrogen, viz., ammonium sulphate, ammonium sulphate-nitrate, Chilean nitrate, groundnut cake and ammonium sulphate + groundnut cake, have been found to be equally effective. Half the dose of nitrogenous fertilizer may be applied 5–7.5 cm deep just at planting in a single band, 5–7.5 cm away from the plant and remaining half as top-dressing, six to seven weeks after transplanting.

Hukka tobacco. Hukka tobacco is manured with farmyard manure at 37,650–50,200 kg per hectare, with or without groundnut cake. Sometimes sheep and goat folding is done.

Manuring of *N. tabacum*: At Ferozepur (Punjab), application of 112 kg N per hectare appeared to be the optimum. Higher doses caused some injury to the crop. The doses of farmyard manure could be safely reduced to 12,550–25,100 kg per hectare by supplementing it with nitrogen. At Pusa (Bihar), 56–168 kg N per hectare was found to be the optimum depending upon soil fertility. At Dinhatta (West Bengal), 112–168 kg N per hectare gave the best results. Phosphate application did not influence the crop performance and potassium tended to depress the yield.

Nitrogen can best be applied in two doses, half at planting and half before flowering, to avoid injury to the plants and to obtain the best response.

In the experiments at Ferozepur, the different sources of nitrogen gave almost similar performance. At Dinhatta, early planting (in October) and close spacing 60 cm × 60 cm were the most responsive to nitrogen manuring.

Manuring of *N. rustica*.* At Ferozepur, 56–112 kg N per hectare was found to be the optimum. In recent experiments at the Indian Agricultural Research Institute, New Delhi, the optimum dose was about 134.4–224 kg N per hectare over a basal dose of farmyard manure at the rate of ten cartloads per 0.45 ha. At Dinhatta, 168 kg N per hectare over a basal dose of 5,020–7,530 kg of farmyard manure per hectare gave the best results. Phosphate was generally without effect in the experiments at the I.A.R.I., potassium tended to depress the yield.

Different sources of nitrogen gave almost similar performance.

Fractional application, half at transplanting and half at flowering, was most effective. Application of fertilizers in the plough furrow was better than broadcast application.

Bidi tobacco

Seed-bed manuring. Experiments at the Bidi Tobacco Research Station, Anand, have shown that farmyard manure to supply 44.8 kg N per hectare plus castor-cake to supply 134.4 kg N per hectare, gave the best results. Castor-cake should be mixed with soil at least a week before sowing. If the growth of seedlings is unsatisfactory, sulphate of ammonia at the rate of 22.4 kg N per hectare should be applied when seedlings are three to four-week old. The application is to be repeated seven to ten days later, if necessary.

Manuring in the field: The general practice is to apply 25 tonnes of farmyard manure per ha with the onset of monsoon rains. Oilcake (groundnut or castor), 362.8–453.5 kg is also applied. Some farmers apply, in addition, 179.2 kg|ha ammonium sulphate 10–15 days after transplanting.

Experiments at Bidi Tobacco Research Station, Anand, have shown that on *goradu* soils, 179.2 kg|ha is the optimum economical limit. P and K were not found to produce a favourable effect on the growth and the quality. Oilcakes and nitrogenous fertilizers were better sources of nitrogen than farmyard manure. Half the dose of nitrogen could be applied as groundnut cake and the other half as nitrogenous fertilizers. Of the fertilizers, ammonium sulphate was the best, closely followed by urea. Chilean nitrate was not suitable. Sheep folding (5,000 units) was found to be as good as 179.2 kg N per hectare. Tobacco stem-dust was not found to be a suitable source of nitrogen.

Drilling half the dose of groundnut cake at 5 to 7.5 cm depth and the other half at 7.5 to 10 cm depth proved superior to broadcast application. The entire dose of the fertilizers should be applied before transplanting.

Conditions influencing fertilizer response: A good crop stand, timely planting, control of *Orobanche* (a root parasite), timely de-suckering (in the types which are topped), moisture conservation and deep placement of fertilizers in the crops which are not irrigated, and optimum irrigation in the types which are irrigated are specially important for obtaining the best response to fertilizers.

FODDERS AND GRASSES

The fodder crops grown in India may be divided into five classes:

Kharif legumes: Cowpeas, *moth*, *kulthi*, *guar*, sannhemp
Kharif non-legumes: Maize, *jowar*, Sudan grass, *bajra*, teosinte, swank, *ragi*
Rabi legumes: Berseem, *senji*, *shaftal*, *methri*, field peas, *val*, *pillipesara*
Rabi non-legumes: Oats, *rabi jowar*, rape, turnip
Perennial legumes: Lucerne
Perennial grasses: Napier grass, Guinea grass, Sudan grass, Para grass, Khodes grass.

The annual fodders may be grown pure or a non-legume and a legume may be grown mixed. For example, the common mixtures are maize and cowpeas, *jowar* and *guar*, berseem and rape, berseem and oats, and oats and peas. In the case of grasses too, legumes could be intersown to obtain more nutritious fodder and increase fodder yield. Mixtures of Rhodes grass and lucerne, Napier grass and *senji*, Para grass and cowpeas, Para grass and vetch may be mentioned.

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*Certain wells in the Punjab and U.P. are reported to contain considerable amounts of nitrates. The quality of irrigation water should, therefore, be taken into account in fixing the dose of nitrogen for *hukka* tobacco.

Kharif fodders may be grown in the monsoon season without irrigation but they are irrigated when grown in early summer. *Rabi* fodders are invariably irrigated.

Annual fodders are quick-growing crops and are grown under conditions of assured rainfall or irrigation and have sometimes to be taken as a catch crop so that a main crop in the rotation is not sacrificed. They should, therefore, be manured liberally. Some of the growers generally apply heavy doses of farmyard manure or dung. Fertilizer use is generally restricted. There is considerable scope for fertilizer use in these crops to improve the yield and the quality of crops, and reduce the requirements of farmyard manure.

In the case of legumes, annuals or perennials, the dose of nitrogen could be reduced to the barest minimum. Except in legumes, such as berseem and lucerne, where application of a low dose of nitrogen is desirable, it is not necessary to apply a nitrogenous fertilizer. It is, however, essential to apply liberal doses of superphosphate. Application of potassium may not be always necessary as application of farmyard manure at ten tons per acre may supply the needs of these crops for potassium.

On acid soils, as in the hills and plateau areas, the soil must be treated with lime not only to correct the soil acidity for improving the rhizobial population, nodulation and growth of the legume, but also for improving the uptake of calcium by the crop and the quality of fodder. Lime requirements of the soil could be worked out with the aid of soil tests.

In the case of non-leguminous fodders, the principal need of the crop is nitrogen in substantial amount, which stimulates vegetative growth and increases the protein content. Application of a moderate dose of phosphate is also desirable for balanced growth of the crop and the animals that feed on the fodders. Liming of the acid soils is also necessary to increase the uptake of calcium. In the case of perennial grasses, nitrogen application will be necessary every year.

When legumes and non-legumes are mixed, it would appear to be desirable to apply farmyard manure in substantial quantity and give only supplementary dose of nitrogen and phosphate in the ratio of the relative area expected to be occupied by the non-legume and the legume on full growth.

Manurial requirements of important fodders

Cowpea: Cowpea is sown during April to September alone or in association with maize, and harvested in about two to two and a half month after sowing. Irrigation is necessary in the crop grown in the pre-monsoon season. Superphosphate at the rate of 30–40 kg P_2O_5 per hectare should be applied in the case of pure crops before sowing.

Guar: It is relatively more drought resistant than cowpea and is susceptible to excess water. Its cultivation is restricted to the western parts of India. Application of phosphate not only increases yield of *guar*, but also that of the succeeding *rabi* crops. A dose of 40–60 kg P_2O_5 per hectare may be given.

Maize: Maize is sown from middle of March to end of July. The fodder is ready in about two months. It requires heavy manuring and adequate moisture supply, but cannot stand water-logging. Farmyard manure at 15.24–20.32 tonnes|ha or 60–80 kg|ha, in the form of nitrogenous fertilizers may be applied in two split doses. In the absence of farmyard manure, superphosphate may also be applied specially if cowpea or velvet beans are sown mixed with maize.

Jowar: It is grown extensively both under rainfed and irrigated conditions alone or mixed with legumes, such as cowpea, *guar*, *moth* and *mung*. It is sown during April to early August. For pure crop, 80 kg N|ha may be applied.

Sudan grass: The crop, when sown in March in North India, gives half a dozen cuttings and matures during October-November. Application of 100–120 kg N|ha may be made in three equal instalments during spring till the middle of August.

Berseem: Berseem is grown under irrigation in the Punjab extensively and is becoming increasingly popular in the adjoining States as well. It is sown after maize or *jowar* fodder which releases the field, relatively early, for timely sowing of the crop in October. On fields where berseem is grown for the first time, seed inoculation with *Rhizobium* culture is essential. The culture can be obtained from the Chemist, Bacteriologist or Micro-biologist of the State or from the Division of Microbiology, I.A.R.I., New Delhi. If culture is not available, about 100 kg of surface soil from a field cropped with berseem in a previous year may be spread uniformly on the field. At least 10.16 tonnes of farmyard manure per hectare, if available, may be applied a few days before sowing. A day or so before sowing 80–100 kg P_2O_5|ha as superphosphate should be applied and incorporated in the soil with ploughing. At the time of sowing 15–20 kg N in the form of a nitrogenous fertilizer may also be applied. If oats or *sarson* are sown mixed with berseem, the dose of nitrogen may be increased. Frequent irrigations are necessary for obtaining good fertilizer response and high yields.

Senji and Methra: They are usually sown after maize or intersown with cotton. The crops have lower irrigation requirements than berseem and are, therefore, preferred under conditions where water supplies are inadequate. They are usually grown without fertilizers and manures. When grown after maize, 30–40 kg P_2O_5|ha may be applied before sowing of the fodders. When intersown in cotton it would appear to be desirable to drill the phosphate before the sowing of cotton.

Oats: It is sown during October-December as an irrigated *rabi* crop after maize, *jowar*, cowpea or *guar*. A dose of 60–80 kg N|ha should be split and one-half applied before sowing and the rest after the first cutting. Oats can also be sown as mixture with common vetch (*Vicia sativa*), peas, *senji*, lucerne and berseem. In such cases it is imperative that application of phosphate is not omitted.

Teosinte: Teosinte is closely related to cultivated maize and requires rich, well-drained soil. 60–80 kg N|ha may be applied in two equal splits, the first before sowing and the rest when the crop is knee-high.

Perennial fodders

Lucerne: Once established, it can give green fodder for three or four years for most of the year. Farmyard manure at the rate of 20 tonnes or more depending upon availability per hectare can be applied a month before sowing. Before sowing 100–120 kg P_2O_5|ha in the form of superphosphate (single) may be drilled. Subsequently, in September every year, superphosphate may be drilled in between the lucerne rows. The crop should be irrigated frequently and kept free of weeds to obtain maximum response to the manures and fertilizers.

Napier or Elephant grass: It requires warm and moist climate and can be grown on a variety of soils. Being a heavy yielder, 15–20 tonnes|ha of well-rotted farmyard manure and 60–80 kg P_2O_5|ha in the form of superphosphate (single) should be applied before planting. This should be followed by top-dressing annually with nitrogen at 150–180 kg|ha in three or four equal doses. The crop can be intercropped with annual grasses and legumes during winter when Elephant grass is dormant.

Pusa Giant Napier: A hybrid between Napier grass and *bajra* has been recently released. It gives very high yield and responds to heavier doses of manures and fertilizers. About 200–250 kg N|ha in combination with 60 kg of P_2O_5 and 60 kg of K_2O may be applied for realizing the full potential according to the growth capacity of the hybrid.

Para grass: It can grow under conditions of excess water and requires frequent irrigations. Under sewage irrigation it has given as high as 2,100 q|ha yield in seven cuttings. It responds to heavier doses of N. About 15.24–20.32 tonnes of farmyard manure|ha supplemented by 120–150 kg N may be applied. The fertilizers may be applied in three or four equal instalments.

Rhodes grass: About 10.16–15.24 tonnes of farmyard manure, 100–120 kg N and about 40 kg P_2O_5 per hectare should be applied. The nitrogen may be applied in two equal doses, one after spring and the other after commencement of the monsoon.

APPENDICES

LIST OF APPENDICES

Appendix No.	*Subject*
1.	Average analysis of important plant food materials and amendments.
2.	Mixing of fertilizers.
3.	Location and quality of limestone available in the country.
4.	Neutralizing values of different liming materials.
5.	Equivalent acidity of some of the commonly used fertilizers.
6.	Limestone conversion factors.
7.	Uptake of calcium by plants and crops.
8.	Relative availability in the soil of limestone particles of different degrees of fineness.
9.	Approximate amounts of finely-ground limestone needed to raise the pH of an 13-cm layer of soil.
10.	Agricultural lime requirement for different types of soil in India.
11.	Optimum pH range of crops.
12.	Conversion of pure nutrients to quantity of fertilizers.
13.	Conversion table—price per tonne of fertilizer to price per kg of nutrient.
14.	Plant nutrients removed by important crops.
15.	Himalayan forest soil (Chaubattia, U.P.)—composition.
16.	*Terai* soil (Matkota Farm, U.P.)—composition.
17.	Alluvial soil (Indo-Gangetic)—composition.
18.	Gangetic alluvium (Calcareous)—composition.
19.	Gangetic alluvium (Ghatampur, U.P.)—composition.
20.	Composition of *regur* or black soil (Akola Experimental Farm, M.P.)—composition.
21.	Soil profile from alluvial soils, Salem (Madras)—composition.
22.	Laterite soil from Angadipuram (Kerala)—composition.
23.	Red loam from Kasargod (Kerala)—composition.
24.	'Kari' soil (Peaty soil) from Kuttanad Area (Kerala State, near Thottapally Spillway)—composition.

APPENDIX 1. AVERAGE ANALYSIS OF IMPORTANT PLANT FOOD MATERIALS AND AMENDMENTS

Material	Nitrogen (N)	Phosphoric acid (P_2O_5)	Potash (K_2O)
Fertilizers			
Nitrate of potash (70 %)	8–10	..	30.33
Ammonium phosphate (60%)	17–18	20–21	..
Urea	46	..	..
Nitrate of soda	15–16	..	..
Ammonium sulphate	20.6	..	..
Ammonium sulphate-nitrate	26 19.5 (NH_3–N) and 6.5 (NO_3–N)	..	..
Ammonium nitrate	32–33 (half NO_3 and half NH_3)	..	..
Calcium cyanamide	18–20	..	..
Calcium nitrate	15–16	..	..
Nitroline	20–21	..	..
Superphosphate (single)	..	16–20	..
Hyperphosphate	..	26 (90% citrate soluble)	..
Basic slag	..	14–18	..
Superphosphate (concentrated)	..	40–50	..
Mineral phosphate (various grades)	..	25–36	..
Muriate of potash	..	..	60
Sulphate of potash	..	..	48–52
Liquid ammonia	82.2	..	..
Organic manures			
Castor-cake	4.3	1.8	1.3
Cottonseed cake (undecorticated)	3.9	1.8	1.6
Karanj or *honge* cake	3.9	0.9	1.2
Mathua or *ippi* cake	2.5	0.8	1.8
Neem cake	5.2	1.0	1.4
Safflower cake (undecorticated)	4.9	1.4	1.2
Coconut cake	7.3	1.5	1.8

APPENDIX 1. (*Concld*)

Material	Nitrogen (N)	Phosphoric acid (P_2O_5)	Potash (K_2O)
Fambo cake	4.9	1.6	1.9
Linseed cake	5.5	1.4	1.3
Niger cake	4.7	1.8	1.3
Rapeseed cake	5.2	1.8	1.2
Safflower cake (decorticated)	7.9	2.2	1.9
Sesamum or *til* cake	6.2	2.0	1.2
Manures of animal origin			
Dried blood	10.0	1.5	1.0
Fish manures	4.0–10.0	3.0–9.0	0.3–1.5
Bone-meal (raw)	3.0–4.0	20.0–25.0	..
Bone-meal (steamed)	1.0–2.0	25.0–30.0	..
Bulky organic manures			
Farmyard manure	0.5–1.5	0.4–0.8	0.5–1.9
Compost (urban)	1.0–2.0	1.0	1.5
Compost (rural)	0.4–0.8	0.3–0.6	0.7–1.0
Green manure (various analysis)	0.5–0.7	0.1–0.2	0.8–1.6
Nitre earth	5.8% (NO_3)	..	..
Sea bittem	..	..	5–15
Monoammonium phosphate	11.0	48 (water soluble)	..
Diammonium phosphate	21.0	53 („)	..
Dicalcium phosphate	..	34 (citrate soluble)	
Kotka phosphate	..	16 (water sol. + citrate sol.)	..
ODDA nitrophosphate	20	20 (half water sol., half citrate sol.)	.. ..
PEC	16	20 (citrate sol.)	..
Trichy phosphate	..	30–35 (total P_2O_5)	..
Singhbhum phosphate	..	20–25 („)	
Basic slag	..	4–8 („)	
Calcium materials (Calcium per cent, CaO)			
Basic slag		40–45	
Limestone		40–45	
Gypsum (80% pure)		30–33	

APPENDIX 2. MIXING OF FERTILIZERS

	Hyperphosphate	Kainite, 40% potash salts, 50% potash salts, and 60% potash salts	Potash magnesia (Patentkali), sulphate of potash	Rhenania phosphate	Basic slag	Superphosphate	Calcium cyanamide	Sulphate of ammonia	Calcium ammonium nitrate	Ammonium sulphate-nitrate	Sodium nitrate	Calcium nitrate
Calcium nitrate	0	0	0	0	0	×	0	0	0	0	0	+
Sodium nitrate	0	+	+	+	+	0	0	+	0	+	+	0
Ammonium sulphate-nitrate	+	0	+	0	×	+	×	+	+	+	+	0
Calcium ammonium nitrate	+	0	0	0	×	0	×	+	+	+	0	0
Sulphate of ammonia	+	+	+	0	×	+	×	+	+	+	+	0
Calcium cyanamide	+	0	+	+	+	×	+	×	×	×	0	0
Superphosphate	+	+	+	×	×	+	×	+	0	+	0	×
Basic slag	+	+	+	+	+	×	+	×	×	×	+	0
Rhenania phosphate	+	+	+	+	+	×	+	0	0	0	+	0
Potash magnesia (Patentkali), sulphate of potash	+	+	+	+	+	+	+	+	0	+	+	0
Kainite, 40% potash salts, 50% potash salts and 60% potash salts	+	+	+	+	+	+	0	+	0	0	+	0
Hyperphosphate	+	+	+	+	+	+	+	+	+	+	0	0

+ = Fertilizers which can be mixed

× = Fertilizers which cannot be mixed

0 = Fertilizers which can be mixed but must be applied within three days, at the most, after mixing.

APPENDIX 3. LOCATION AND QUALITY OF LIMESTONE AVAILABLE IN THE COUNTRY

State	District	Analysis: Per cent			Remarks
		SiO_2	CaO	MgO	
Andhra Pradesh	Kurnool, Hyderabad and Vishakhapatnam	10–13	46–47	Trace–0.9	
Assam	Khasi Hills and Garo Hills	0,5–2	50–53	0.7–1	
Bihar	Sahabad, Hazaribagh, Palamau and Singhbhum	8–15	44–50	0.5–2	Silicious
Gujarat	Junagadh and Banas	0,8–4	51–53	0.6–0.9	Chalk
Madhya Pradesh	Jabalpur, Durg and Bilaspur	1–9	40–53	0.2–2	
Tamil Nadu	Tiruchirapalli, Nellore, Salem, Madurai and Ramanathapuram	0.5–2	53–54	0.2–8	Crystalline limestone
Maharashtra	Mudhol (not district) and Yoetmal	1.6	50–54	Trace–3	
Mysore	Shimoga, Chitaldrug, Tumkur, Mysore and Bijapur	2	50	1	Crystalline
Orissa	Sundargarh, Sambalpur and Koraput	1–10	49–53	0.5–3	Dolomitic
Punjab	Patiala and Ambala	3–3	51–53	1–1	..
Rajasthan	Dund, Jodhpur and Udaipur	7–15	44–45	0.1–0.9	..
Uttar Pradesh	Mirzapur, Dehra Dun and Mussourie (not district)	..	..	..	..
West Bengal	Darjeeling (Western *Duars*)				Crystalline (at present inaccessible dolomitic)

APPENDIX 4. NEUTRALIZING VALUES OF DIFFERENT LIMING MATERIALS ($CaCO_3$ as 100)

Limestone (natural) ..	57–95
Calcium hydroxide	135
Calcium oxide	178
Magnesium oxide	250
Magnesium carbonate	119
Wood-ash	30–70

APPENDIX 5. 'EQUIVALENT ACIDITY'* OF SOME OF THE COMMONLY USED FERTILIZERS

Fertilizer	Per cent N	Equivalent acidity
Ammonia, anhydrous	82.0	148
Ammonium chloride	24.0	128
Ammonium nitrate	33.5	60
Ammonium nitrate-limestone†	20.5	0
Ammonium sulphate	20.5	110
Ammonium sulphate-nitrate	26.0	93
Urea	45.0	80

*'Equivalent acidity' is the number of parts by weight of calcium carbonate ($CaCO_3$) required to neutralize the acidity resulting from the use of 100 parts of the fertilizer material. For example, ammonium sulphate has an equivalent acidity 110. It takes, therefore, 110 kg of calcium carbonate to neutralize the acidity developed in the soil by the use of 100 kg of ammonium sulphate fertilizer.

†Cal-Nitro, A-N-L, calcium ammonium nitrate and other names.

APPENDIX 6. LIMESTONE CONVERSION FACTORS

Per cent		Per cent		Factor
Ca	to	CaO	Multiplied by	1.40
Ca	to	$Ca(OH)_2$	"	1.85
Ca	to	$CaCO_3$	"	2.50
Mg	to	MgO	"	1.67
Mg	to	$Mg(OH)_2$	"	2.42
Mg	to	$MgCO_3$	"	3.50
Mg	to	Ca	"	1.67
Mg	to	$CaCO_3$	"	4.17
MgO	to	$CaCO_3$	"	2.50
$MgCO_3$	to	$CaCO_3$	"	1.19

APPENDIX 7. UPTAKE OF CALCIUM BY PLANTS AND CROPS

Name of crop plant	Average yield (kg per 0.45 hectare)	Amount (kg) of calcium removed per 0.45 hectare	
		Ca	$CaCO_3$
Berseem	18,636 (entire crop)	52.3	130.7
Coffee	For 100 young *Cassia-arabica* bushes during 5th year of growth ..	5.5	13.7
Cotton	2,727 (cotton and stick) ..	20.4	51.0
Groundnut	1,682 (entire crop) ..	29.5	73.7
Lemon	For 160 trees	103.0	258.0
Maize	2,727 (grains and straw) ..	40.0	100.0
Orange	For 160 trees	90.0	227.0
Paddy	2,727 (grains and straw) ..	14.5	36.2
Pineapple	For 32 tonnes	128.0	310.0
Potato	11,363 (entire crop) ..	34.0	85.0
Sugarcane	18,636 (entire crop) ..	16.3	41.0
Tea	For 1,000 kg. of made tea ..	5.0	12.5
Tobacco	773 (dry leaves and stalk) ..	63.6	159.0
Wheat	1,818 (grains and straw) ..	10.0	25.0

APPENDIX 8. RELATIVE AVAILABILITY IN THE SOIL OF LIMESTONE PARTICLES OF DIFFERENT DEGREES OF FINENESS

Fineness of particles	Percentage available within	
	1–3 yrs	8–12 yrs
Held on 20-mesh screen	20	50
Through 20-mesh screen but held on 60-mesh screen	60	100
Through 60-mesh screen	100	100

APPENDIX 9. APPROXIMATE AMOUNTS OF FINELY GROUND LIMESTONE* NEEDED TO RAISE THE pH OF AN 18-CM LAYER OF SOIL

Soil regions and texture	Limestone requirements (kg per 0.45 hectare†)		
	From pH 3.5 to 4.5	From pH 4.5 to 5.5	From pH 5.5 to 6.5
Soils of warm-temperate and tropical regions ‡			
Sand and loamy sand	243	243	364
Sandy loam	§	446	610
Loam	§	683	890
Silt loam	§	1,100	1,300
Clay loam	§	1,375	1,740
Muck	2,260	3,040	3,480

*All through a 2 mm-mesh screen and at least one-half through a 0.15 mm-mesh screen. With coarser materials application should be greater.

†The suggestions for muck soils are for those essentially free of sand and clay. For those containing much sand or clay the amounts should be reduced to values midway between those given for muck and the corresponding class of mineral soil. If the mineral soils are usually low in organic matter, the recommendations should be reduced by about 25 per cent and if unusually high should be increased by about 25 per cent.

‡Red-yellow podsolic, red latosol, etc.

§No recommendation given.

APPENDIX 10. AGRICULTURAL LIME REQUIREMENT FOR DIFFERENT TYPES OF SOILS IN INDIA

Sl. No.	Soil	pH	Total area (million acres)*	Cultivated area (million acres)*	Lime requirement for acid soils only (million metric tons/year)
1.	Strongly acid ..	Below 5.5	64.0	16.0	5.5
2.	Slightly acid ..	5.6–6.5	58.4	20.4	4.6
3.	Neutral ..	6.6–7.5	114.0	..	..
		Total	236.4	36.4	10.1

* one acre = 0.405 hectare.

APPENDIX 11. OPTIMUM pH RANGE OF CROPS

Crop	Optimum pH range
Barley	6.5–8.0
Sugar-beet	6.5–8.0
Banana	6.0–7.5
Coconut palm	6.0–8.0
Cotton	5.0–6.0
Groundnut	5.3–6.6
Maize	5.5–7.5
Rice	5.0–6.5
Soybean	6.0–7.0
Sugarcane	6.0–8.0
Sunflower	6.0–7.5
Tobacco	5.5–7.5
Wheat	5.5–7.5

APPENDIX 12. CONVERSION OF PURE NUTRIENTS TO QUANTITY OF FERTILIZERS

Percentage of nutrient in fertilizer	Quantity of fertilizer required (kg)						
	Rate of application of pure nutrient (kg)						
	10	20	30	40	50	60	70
1	1,000	2,000	3,000	4,000	5,000	6,000	7,000
2	500	1,000	1,500	2,000	2,500	3,000	3,500
3	335	670	1,000	1,330	1,670	2,000	2,330
4	250	500	750	1,000	1,250	1,500	1,750
5	200	400	600	800	1,000	1,200	1,600
6	165	330	500	670	830	1,000	1,270
7	145	290	430	570	710	860	1,000
8	125	250	375	500	625	750	875
9	110	220	330	440	560	670	780
10	100	200	300	400	500	600	700
11	90	180	270	360	450	540	630
12	85	170	250	330	420	500	580
13	75	150	230	310	390	460	540
14	70	140	218	180	360	430	500
15	65	130	208	270	340	400	470
16	65	130	190	250	310	380	440
17	60	120	180	240	290	350	410
18	55	110	170	220	280	330	390
19	55	110	160	210	260	320	370
20	50	100	150	200	250	300	350
21	50	100	140	190	240	290	330
22	45	90	140	180	230	270	320
23	45	90	130	180	220	260	310
24	40	84	130	170	210	250	290
25	40	80	120	160	200	240	280
26	40	80	120	160	200	230	270
27	35	75	110	150	185	220	260
28	35	70	105	145	180	215	250
29	35	70	105	140	175	210	240
30	35	65	100	135	165	200	235
31	30	65	100	130	160	195	225
32	30	65	95	125	155	190	220

APPENDIX 12. (*Contd*)

Percentage of nutrient in fertilizer	Quantity of fertilizer required (kg)						
	Rate of application of pure nutrient (kg)						
	10	20	30	40	50	60	70
33	30	60	90	120	150	180	210
34	30	60	85	120	150	175	205
35	30	55	85	115	145	170	200
36	30	55	85	110	140	165	195
37	25	55	80	110	135	160	190
38	25	55	80	105	130	160	185
39	25	50	75	100	130	155	180
40	25	50	75	100	125	175	175
41	25	50	75	95	120	145	170
42	25	50	70	95	120	145	170
43	25	45	70	95	120	140	165
44	25	45	70	90	115	135	160
45	20	45	70	90	110	130	155
46	20	45	65	85	110	130	150
47	20	45	65	85	110	130	150
48	20	40	60	85	105	125	145
49	20	40	60	80	100	120	145
50	20	40	60	80	100	120	140
51	20	40	60	80	100	120	140
52	20	40	60	75	95	115	135
53	20	40	55	75	95	115	130
54	20	35	55	75	95	110	130
55	20	35	55	75	90	110	125
56	20	35	55	70	90	105	125
57	20	35	55	70	90	105	125
58	15	35	50	70	85	105	120
59	15	35	50	70	85	100	120
60	15	35	50	65	85	100	115

APPENDIX 12. (*Contd*)

Percentage of nutrient in fertilizer	Quantity of fertilizer required (kg)						
	Rate of application of pure nutrient (kg)						
	80	90	100	200	300	400	500
1	8,000	9,000	10,000	20,000	30,000	40,000	50,000
2	4,000	4,500	5,000	10,000	15,000	20,000	25,000
3	2,670	3,000	3,330	6,670	10,000	13,320	26,680
4	2,000	2,250	2,500	5,000	7,500	10,000	12,500
5	1,600	1,800	2,000	4,000	6,000	8,000	10,000
6	1,330	1,500	1,670	3,330	5,000	6,700	8,300
7	1.140	1,290	1,430	2,860	4,300	5,700	7,100
8	1,000	1,125	1,250	2,500	3,750	5,000	6,250
9	890	1,000	1,110	2,220	3,330	4,440	5,550
10	800	900	1,000	2,000	3,000	4,000	5,000
11	720	810	900	1,800	2,700	3,600	4,500
12	670	750	830	1,700	2,500	3,300	4,200
13	620	690	770	1,540	2,310	3,100	3,850
14	570	640	710	1,420	2,130	2,740	3,550
15	540	600	770	1,340	2,010	2,080	3,350
16	500	560	625	1,250	1,880	2,500	3,130
17	470	530	590	1,180	1,760	2,350	2,940
18	440	500	560	1,110	1,670	2,220	2,780
19	420	470	530	1,050	1,580	2,100	2,630
20	400	450	500	1,000	1,500	2,000	2,500
21	380	430	480	950	1,430	1,900	2,380
22	360	410	460	910	1,370	1,820	2,280
23	350	390	440	870	1,300	1,740	2,170
24	330	380	420	830	1,250	1,670	2,080
25	320	360	400	800	1,200	1,600	2,000
26	310	350	380	770	1,160	1,540	1,930
27	300	335	370	740	1,110	1,480	1,850
28	285	325	355	715	1,070	1,430	1,785
29	275	310	345	690	1,035	1,380	1,725
30	265	300	335	665	1,000	1,335	1,665
31	255	290	325	645	970	1,290	1,615
32	250	280	315	625	940	1,250	1,565
33	240	275	305	605	910	1,210	1,515

APPENDIX 12. (*Concld*)

Percentage of nutrient in fertilizer	Quantity of fertilizer required (kg)						
	Rate of application of pure nutrient (kg)						
	80	90	100	200	300	400	500
34	235	265	295	590	880	1,175	1,479
35	230	255	285	575	860	1,145	1,430
36	220	250	280	555	835	1,110	1,390
37	215	245	270	540	810	1,080	1,350
38	210	240	260	525	790	1,050	1,315
39	205	230	255	510	770	1,025	1,280
40	200	225	250	500	750	1,000	1,250
41	195	220	245	490	730	975	1,220
42	190	215	240	475	715	950	1,190
43	185	210	235	465	700	930	1,165
44	180	205	225	455	680	910	1,135
45	180	200	220	445	665	890	1,110
46	175	195	215	435	650	870	1,085
47	170	190	215	425	640	850	1,065
48	165	185	205	415	625	835	1,040
49	165	185	205	410	610	815	1,020
50	160	180	200	400	600	800	1,000
51	160	175	195	390	590	785	980
52	155	175	190	385	570	770	960
53	150	170	190	375	565	755	945
54	150	165	185	370	555	740	925
55	145	165	180	365	545	730	910
56	145	160	180	355	535	715	890
57	140	160	175	350	525	700	880
58	140	155	175	345	520	690	860
59	135	155	170	340	510	680	850
60	135	150	165	335	500	670	835

APPENDIX 13. CONVERSION TABLE—PRICE PER TON OF FERTILIZER TO PRICE PER POUND OF NUTRIENT

(Price per pound of nutrient in P.)

Per cent nutrient content price per long ton of fertilizer (Rs)	10	11	12	13	14	15	16
150	67.0	60.9	55.8	51.5	47.8	44.6	41.8
155	69.1	62.9	57.6	53.2	49.4	46.1	43.2
160	71.4	64.9	59.5	54.9	51.0	47.5	44.6
165	73.6	76.9	61.4	56.7	52.6	49.1	46.0
170	75.9	68.9	63.2	58.4	54.2	50.6	47.4
175	78.1	71.0	65.1	60.1	55.8	52.1	48.8
180	80.4	73.0	66.9	61.8	57.4	53.6	50.2
185	82.6	75.1	68.8	63.5	59.0	55.1	51.6
190	84.8	77.1	70.7	65.2	60.6	56.5	53.0
195	87.1	71.9	72.5	66.9	62.2	58.0	54.4
200	89.3	81.2	74.4	68.7	63.8	59.5	55.8
210	93.8	55.2	78.1	72.1	67.0	62.5	58.6
220	98.2	89.3	81.8	75.5	70.2	65.5	61.4
230	102.6	93.3	85.6	79.0	73.4	68.5	64.2
240	107.1	97.4	89.3	82.4	76.5	71.4	67.0
250	111.6	101.5	93.0	85.8	79.7	74.4	69.8
260	116.1	105.5	96.7	89.3	82.9	77.4	72.5
270	120.5	109.6	100.4	92.7	86.1	80.4	75.3
280	125.0	113.6	104.2	96.2	89.3	83.3	78.3
290	..	117.7	107.9	99.6	93.5	86.3	80.9
300	..	121.7	111.6	103.0	95.3	89.3	83.7
325	..	..	120.9	111.6	103.6	96.7	90.7
350	..	..	..	120.2	111.6	104.2	97.7
375	..	..	..	..	119.6	111.6	104.0
400	..	..	..	..	..	119.0	111.6
425	..	..	..	..	..	..	118.6
450	..	..	..	..	..	..	..
500	..	..	..	..	..	..	..
550	..	..	..	..	..	..	..
600	..	..	..	..	..	..	..
650	..	..	..	..	..	..	..
700	..	..	..	..	..	..	..

APPENDIX 13. (*Contd*)

Per cent nutrient content price per long ton of fertilizer (Rs)	17	18	19	20	22	24	26	28
150	39.4	37.2	35.2	33.5	30.4	27.9	25.8	23.9
155	40.7	38.4	36.4	34.6	31.5	28.8	26.6	24.7
160	24.0	39.7	37.4	35.7	32.5	29.8	27.5	25.5
165	43.3	40.9	38.8	36.8	33.5	30.7	28.3	26.3
170	46.6	42.2	39.9	37.9	34.5	31.6	29.2	27.1
175	46.0	43.4	41.1	39.1	35.5	32.6	30.0	27.9
180	47.3	44.6	42.3	40.2	36.5	33.5	30.9	28.7
185	48.6	45.9	43.5	41.3	37.5	34.4	31.8	29.5
190	49.9	47.1	44.6	42.4	38.5	35.3	32.6	30.3
195	51.2	48.4	45.8	43.5	39.6	36.3	33.5	31.5
200	52.5	49.6	47.0	44.6	40.6	37.2	34.3	31.9
210	55.1	52.1	49.3	46.9	42.6	39.1	36.1	33.5
220	57.8	54.6	51.7	49.1	44.6	40.9	37.8	35.1
230	60.4	57.0	54.0	51.3	46.7	42.8	39.5	36.7
240	63.0	59.5	56.4	53.6	48.7	44.6	41.2	38.3
250	65.7	62.0	58.4	55.8	50.7	46.5	42.9	39.9
260	68.3	64.5	61.1	58.0	52.8	48.4	44.6	41.5
270	70.9	66.0	63.4	60.3	54.8	50.2	46.4	43.0
280	73.5	69.4	65.8	62.5	56.8	52.1	48.1	44.6
290	76.2	71.9	68.1	64.7	58.8	53.9	49.8	46.2
300	78.8	74.4	70.5	67.0	60.9	55.8	51.5	47.8
325	85.3	80.6	76.4	72.5	65.9	60.5	55.8	51.8
350	91.9	86.8	82.2	78.1	71.0	65.1	60.1	55.8
375	98.5	93.0	88.1	83.7	76.1	69.8	94.4	59.8
400	105.0	99.2	93.9	89.3	81.3	74.4	68.7	63.8
425	111.6	105.4	99.9	94.9	86.2	79.1	73.0	67.8
450	118.2	111.6	105.7	100.4	91.3	83.7	77.3	71.7
500	..	..	177.5	111.6	101.5	93.0	85.9	79.7
550	..	..	..	..	111.6	102.3	94.4	36.1
600	..	..	..	..	..	111.6	103.0	95.7
650	..	..	..	..	..	..	111.6	103.6
700	..	..	..	..	..	..	..	111.6

APPENDIX 13. (*Contd*)

Per cent nutrient content price per long ton of fertilizer (Rs)	30	32	34	36	38	40
170	25.3	23.7	22.3	21.1	..	..
175	26.0	24.4	23.0	21.7	..	..
180	26.8	25.1	23.6	22.3	21.1	..
185	27.5	25.8	24.3	22.9	21.7	..
190	28.3	26.5	24.9	23.6	22.8	21.2
195	29.0	27.2	25.6	24.2	22.5	21.8
200	29.8	27.9	26.3	24.8	23.5	22.3
210	31.3	29.3	27.6	26.0	24.7	23.4
220	32.7	30.7	28.9	27.3	25.8	24.6
230	34.2	32.1	30.2	28.5	27.0	25.7
240	35.7	35.5	31.5	29.8	38.2	26.8
250	37.2	34.6	32.8	31.0	29.4	27.9
260	38.7	36.3	34.1	32.2	30.5	29.0
270	40.2	37.7	35.5	33.5	31.7	30.1
280	41.7	39.1	36.8	34.7	32.9	31.2
290	43.2	40.5	38.1	36.0	34.1	32.4
300	44.6	41.9	39.4	37.2	35.2	33.5
325	48.4	45.3	42.7	40.3	38.2	36.3
350	52.1	48.8	46.0	43.4	41.1	39.1
375	55.8	52.3	49.2	46.5	44.6	41.9
400	59.5	55.8	52.5	46.6	46.9	44.6
425	63.2	59.3	55.8	52.7	49.9	47.4
450	67.0	62.8	59.1	55.8	52.9	50.2
500	74.4	69.8	65.7	62.0	58.7	55.8
550	81.8	76.7	72.2	68.2	64.6	61.4
600	89.3	83.7	78.8	74.4	70.5	67.0
650	96.7	90.7	85.3	80.7	76.4	72.5
700	104.2	97.7	91.9	86.8	82.2	78.1
750	111.6	104.6	98.5	92.0	88.1	83.7
800	119.0	111.6	105.0	99.2	94.0	89.3
850	126.5	118.6	111.6	105.4	99.9	94.9
900	..	125.6	118.2	111.6	105.7	100.4
950	..	..	..	117.8	111.6	106.0
1000	..	..	..	124.0	117.3	111.6

APPENDIX 13. (*Concld*)

Per cent nutrient content price per long ton of fertilizer (Rs)	45	50	55	60	65	70
170	..	..	..	..	..	..
175	..	..	..	..	..	..
180	..	..	..	..	..	..
185	..	..	..	..	..	..
190	..	..	..	..	..	..
195	..	..	..	..	..	..
200	..	..	..	..	..	..
210	20.8	..	..	..	..	..
220	21.8	..	..	..	..	..
230	22.8	20.5	..	..	..	..
240	23.8	21.4	..	..	..	..
250	24.8	22.3	20.3	..	..	..
260	25.8	23.2	21.1	..	..	..
270	26.8	24.1	21.9	20.1	..	..
280	27.8	25.0	22.7	20.8	..	..
290	28.8	25.9	23.5	21.6	..	..
300	29.8	26.8	24.3	22.3	20.6	..
325	32.2	29.0	26.4	24.2	22.3	20.7
350	34.7	31.2	28.4	26.0	24.0	22.3
375	37.2	33.5	30.4	27.9	25.8	23.9
400	39.7	35.7	32.5	29.8	27.5	25.5
425	42.2	37.9	34.5	31.6	29.2	27.1
450	44.6	40.1	36.5	33.5	30.9	28.7
500	49.6	44.6	40.6	37.2	34.3	31.9
550	54.6	49.1	44.6	40.9	37.8	35.1
600	59.5	53.6	48.7	44.6	41.2	38.7
650	64.5	58.0	52.8	48.4	44.6	41.5
700	69.4	62.5	56.8	52.1	48.1	44.6
750	74.4	67.0	60.9	55.8	54.8	47.8
800	79.3	71.4	64.9	59.5	51.0	51.0
850	84.3	75.9	69.0	63.2	58.4	54.2
900	89.3	80.4	73.1	67.0	61.8	57.4
950	94.2	84.8	77.1	70.7	65.2	60.6
1000	99.2	89.3	81.2	74.4	68.7	63.8

APPENDIX 14. PLANT NUTRIENTS REMOVED BY IMPORTANT CROPS

Crop		Removal of plant nutrients in kg per 0.45 ha			Yield in kg per hectare
		N	P_2O_5	K_2O	
Paddy	Grain	26	14	8	2,000
	Straw	28	8	75	4,000
Wheat	Grain	22	12	7	1,400
	Straw	13	4	35	2,800
Jowar	Grain	14	9	7	1,000
	Straw	12	7	65	3,000
Bajra	Grain	15	6	9	1,800
	Straw	14	4	81	3,000
Maize	Grain	32	17	10	1,000
	Straw	39	12	58	3,600
Barley	Grain	27	12	7	1,500
	Straw	18	6	36	2,500
Cotton	Seed	40	16	16	1,500
	Stalks	35	10	38	2,800
Groundnut	Nuts	45	8	8	4,500
	Stalks	20	4	30	4,500
Sugarcane		150	63	300	67,200

APPENDIX 15, HIMALAYAN FOREST SOIL (CHAUBATIA, U.P.)—COMPOSITION (OVEN-DRY BASIS)

Depth (in cm)	0–5	5–20	20–43	Below 43
Coarse sand (%) ..	2.83	5.94	2.28	0.31
Fine sand (%) ..	22.09	29.53	28.48	20.98
Silt (%) ..	30.75	33.15	40.40	40.75
Clay (%) ..	26.40	22.40	24.15	30.75
Exchangeable H m.e.	Trace	0.525	Trace	Trace
Moisture (%) ..	3.86	2.86	304	3.86
Loss on ignition (%)	13.89	7.96	3.53	4.43
Organic carbon (%)	6.08	2.73	0.47	0.86
Organic N (%) ..	0.44	0.25	0.07	0.08
C/N	13.8	10.8	7.1	11.2
pH	5.9	5.7	5.9	6.2
Insoluble matter (%)	68.1	75.6	78.2	75.0
Fe_2O_3 (%) ..	4.6	4.2	5.8	6.2
Al_2O_3 (%) ..	8.76	8.53	7.88	8.75
R_2O_3 (%) ..	13.39	12.79	13.71	14.96
MgO (%) ..	0.58	0.66	1.01	0.86
CaO (%) ..	0.16	0.08	0.17	0.46

APPENDIX 16. *Terai* SOIL (MATKOTA FARM, U.P.)—COMPOSITION (OVEN-DRY BASIS)

Depth (in cm)	0–20	20–40	40–63.5	63.5–97	97–135	135–180
Coarse sand (%)	0.88	0.86	0.56	1.44	0.55	0.31
Fine sand (%)	20.03	21.14	13.73	14.01	11.44	18.90
Silt (%)	51.63	54.10	59.15	56.70	65.98	57.75
Clay (%)	25.20	23.90	24.00	26.70	21.13	21.50
pH	7.5	6.8	7.2	7.0	6.9	7.1
Organic carbon (%)	1.63	1.02	0.80	0.78	0.61	0.52
Total N	0.178	0.091	0.06	0.083	0.071	0.056
C/N	9.1	11.3	13.4	9.4	8.5	9.2
CaO (%)	0.97	1.20	1.04	1.02	0.91	0.84
Base exchange capacity m.e.	14.75	12.18	11.98	11.73	10.48	9.22

APPENDIX 17. ALLUVIAL SOIL (INDO-GANGETIC)—COMPOSITION (OVEN-DRY BASIS)

Depth (in cm)	0–16	16–105	105–165	165–240	240–270	270–300
Texture	Clayey	Clayey	Clayey	Clayey	Clayey	Clayey
SiO_2 (%)	68.9	66.3	65.7	63.9	69.7	65.9
Al_2O_3 (%)	12.0	12.5	13.4	13.3	11.3	12.0
Fe_2O_3 (%)	9.5	10.0	10.3	10.3	8.8	10.6
CaO (%)	1.9	2.5	1.9	1.8	1.4	1.7
MgO (%)	1.24	1.25	0.98	0.95	0.88	0.80
P_2O_5 (%)	0.16	0.16	0.14	0.14	0.12	0.12
K_2O (%)	0.70	0.68	0.52	0.51	0.40	0.45
Mn (%)	0.06	0.08	0.08	0.09	0.08	0.12
$CaCO_3$ (%)	Nil	Nil	Nil	Nil	Nil	Nil
Organic C (%)	0.47	0.46	0.35	0.32	0.23	0.21
Nitrogen (%)	0.087	0.08	0.055	0.05	0.041	0.03
C/N	5.5	5.7	6.4	6.3	5.7	6.8
pH	7.28	7.12	6.85	6.86	6.46	6.47
Ex. cap. m.e. (%)	9.56	10.8	10.6	8.95	8.2	7.97

APPENDIX 18. GANGETIC ALLUVIUM (CALCAREOUS)—COMPOSITION (OVEN-DRY BASIS)

Depth (in cm)	0–37	37–67	67–82	82–112	112–142	142–180
Loss on ignition (%)	1.78	1.33	1.16	0.53	0.68	1.02
Insoluble material (%)	44.36	36.05	47.51	46.36	44.63	41.75
Fe_2O_3 (%) ..	2.60	2.44	2.16	2.40	2.68	2.90
Al_2O_3 (%) ..	5.40	5.80	3.00	2.60	2.72	2.50
P_2O_5 (%) ..	0.13	0.09	0.11	0.09	0.10	0.08
CaO (%) ..	23.80	27.30	24.22	24.10	24.62	26.90
MgO (%) ..	0.88	0.40	0.78	0.60	1.82	0.98
K_2O (%) ..	0.34	0.42	0.29	0.27	0.22	0.22
C_2O (%) ..	17.80	19.40	18.90	17.10	19.00	20.00
Water-soluble salts (%) ..	0.27	0.20	0.16	0.10	0.17	0.17
Moisture equivalent (%) ..	32.8	32.8	24.0	23.5	30.6	31.0
Water-holding capacity (%)	38.5	48.4	44.2	46.4	52.2	53.8
pH ..	7.9	7.8	7.8	7.8	7.8	7.8
Organic C (%)	0.68	0.47	0.21	0.17	0.18	0.24
Organic N (%)	0.05	0.04	0.04	0.03	0.03	0.03
Exchangeable bases						
Total (m.e.)	6.65	10.47	6.54	19.30	20.96	20.90
Ca (m.e.) ..	5.35	9.85	6.10	18.44	20.40	19.82
Mg (m.e.) ..	0.64	0.30	0.14	0.62	0.34	0.70
Ka + K (m.e.)	0.66	0.32	0.30	0.24	0.22	0.33
H (m.e.) ..	..	..	..	..	..	..
Calcium saturation (%)	80	93	93	95	97	95

APPENDIX 19. GANGETIC ALLUVIUM (GHATAMPUR, U.P.)—COMPOSITION (OVEN-DRY BASIS)

Depth (in cm)	0–30	30–60	60–90	90–120	120–150	150–180
Moisture equivalent (%)	18.73	18.57	18.43	17.36	17.37	16.19
Moisture-holding capacity(%)	46.60	48.82	52.93	54.64	51.89	58.48
pH ..	6.6	6.6	6.7	6.7	6.6	6.8
Total ex. bases m.e. (%) ..	12.40	11.60	13.80	11.40	13.40	11.60
Exchangeable calcium m.e. per cent ..	7.0	8.8	9.2	9.2	8.8	8.6
Calcium saturation (%) ..	56.5	75.8	66.6	80.7	65.6	74.1
Moisture (air-dry %) ..	1.48	1.53	1.75	1.84	1.41	1.15
Loss on ignition (%	1.11	1.46	1.62	2.03	1.77	1.18
HCl insolubles (%) ..	85.92	82.90	79.78	77.95	80.20	82.23
Sesquioxide (%)	8.06	10.40	12.48	13.67	12.71	11.32
CaO (%) ..	0.56	0.56	0.75	0.76	0.72	1.45
MgO (%) ..	8.4	1.37	1.27	1.71	1.71	1.53
K_2O (%) ..	0.67	0.79	0.96	1.10	0.87	0.80
CO_2 (%) ..	Nil	Nil	Nil	Nil	Nil	Nil
Fe_2O_3 (%) ..	3.52	3.32	5.28	6.68	5.36	5.16
P_2O_5 (%) ..	0.22	0.35	0.25	0.16	0.31	0.22
Al_2O_3 (%) ..	3.32	5.73	6.95	7.83	7.04	5.98
Water soluble (%) ..	0.076	0.058	0.043	0.055	0.049	0.051
Carbonates as Na_2CO_3 (%)	Nil	Nil	Nil	Nil	Nil	Nil
Bicarbonates as $NaHCO_3$ (%)	0.034	0.015	0.020	0.020	0.019	0.032

APPENDIX 19. (*Concld*)

Chlorides as NaCl (%) ..	0.013	0.020	0.012	0.008	0.008	0.009
Sulphates as Na_2SO_4 (%)	Nil	Nil	Nil	Nil	Nil	Nil
Organic carbon (%)	0.374	0.164	0.122	0.136	0.117	0.131
Total nitrogen (%)	0.060	0.046	0.031	0.043	0.046	0.031
Coarse sand (%) ..	0.60	0.86	1.17	1.06	0.13	0.11
Fine sand (%)	46.62	44.70	39.11	37.18	44.18	51.55
Silt (%) ..	27.23	24.25	25.48	25.53	21.15	22.45
Clay (%) ..	21.60	28.25	31.95	35.17	28.57	23.80

APPENDIX 20. COMPOSITION OF *regur* OR BLACK SOIL (AKOLA EXPERIMENTAL FARM, M.P.) (OVEN-DRY BASIS)

Depth (in cm)	0–30	30–60	60–90	90–120	120–150	150–180
Clay (%) ..	56.7	56.6	56.3	54.3	50.4	46.6
Silt (%) ..	17.3	19.6	19.7	19.7	23.6	27.7
Fine sand (%)	13.1	12.6	11.7	17.0	19.2	19.8
Coarse sand (%)	2.1	1.9	1.0	0.9	0.6	0.9
$CaCO_3$ (%)	9.5	11.0	10.5	10.5	13.5	7.5
pH ..	7.9	8.0	8.1	8.1	8.1	8.2
Organic C (%)	0.44	0.30	0.21	0.24	0.21	0.21
Available P_2O_5 (kg/0.45 ha)	3.6	2.4	1.8	1.8	0.9	1.3
T.S.S. conducting at 8°C ..	0.45	0.40	0.30	0.35	0.35	0.40
N (%) ..	0.0574	0.0440	0.0386	0.0260	0.0221	0.209

APPENDIX 21. SOIL PROFILE FROM ALLUVIAL SOIL, SALEM (MADRAS)—COMPOSITION (OVEN-DRY BASIS)

Depth (in cm)	0–10	12–25	37–48	48–70
Moisture (%)	6.95	6.82	8.00	7.07
Loss on ignition (%)	14.96	15.25	12.86	14.57
Insoluble residue(%)	55.48	54.34	33.71	47.71
Soluble (by diff.) (%)	37.58	38.84	38.29	45.22
pH	6.6	6.6	6.6	6.4
Lime requirement (cwt CaO/hectare)	0.49	2.05	1.46	0.00
Total N	0.36	0.33	0.25	0.23
Organic carbon (%)	5.15	5.16	3.84	3.45
C/N	14.24	15.97	15.24	15.01
Organic matter (Cdl. 732)	8.90	8.93	6.65	5.97
Total P_2O_5 (%)	0.21	0.18	0.17	0.18
Total K_2O (%)	0.142	0.071	0.090	0.15
Available P_2O_5 (%)	0.0027	0.0021	0.0017	0.0013
Available K_2O (%)	0.0058	0.0050	0.0012	0.0008
CaO (%)	0.714	0.0535	0.268	0.0781
MgO (%)	0.569	0.608	0.475	0.417
T.E.B. m.e./100 gm soil	23.47	17.80	9.221	2.268
R_2O_3 (%)	20.75	21.71	23.26	29.04
SiO_2/R_2O_3	2.67	2.50	2.31	1.64
Clay (%)	20.0	22.50	25.75	34.40
Silt (%)	10.1	11.80	11.05	13.15
Fine sand (%)	12.97	12.13	13.90	11.39
Coarse sand (%)	34.58	29.81	29.18	18.57

APPENDIX 22. LATERITE SOIL FROM ANGADIPURAM (KERALA)—COMPOSITION (OVEN-DRY BASIS)

Depth (in cm)	0–30	30–67	67–165	Below 165
Moisture (%)	1.9	2.3	2.7	2.9
Coarse sand (%)	47.1	43.7	33.7	39.7
Fine sand (%)	21.0	16.7	18.7	19.7
Silt (%)	9.1	11.9	17.6	12.8
Clay (%)	18.9	23.9	26.6	21.6
pH	4.0	4.2	4.6	4.8
Base exch. cap.	5.0	8.0	7.4	5.1
Exchangeable cap.	3.8	3.0	1.5	3.9
Exchangeable Mg	0.8	0.8	1.1	0.9
Exchangeable K	3.1	1.7	1.4	0.9
Quartz (%)	39.46	37.71	38.85	22.65
Soluble SiO_2 (%)	14.08	15.88	17.23	20.81
Al_2O_3 (%)	15.53	13.06	16.24	17.87
Fe_2O_3 (%)	20.32	21.96	15.28	23.88
MgO (%)	0.52	0.31	0.52	0.54
CaO (%)	0.21	0.21	0.22	0.23
K_2O (%)	0.35	0.44	0.45	0.25
TiO_2 (%)	1.25	2.13	2.13	2.25
P_2O_5 (%)	0.26	0.36	0.29	0.54
H_2O_5 (%)	6.69	7.80	7.61	9.27
SiO_2/Al_2O_3	1.55	2.07	1.82	2.24
SiO_2/H_2O	0.94	0.61	0.68	0.68
Available K_2O	Trace	Trace	Trace	Trace
Available P_2O_5	Trace	Trace	Trace	Trace

APPENDIX 23. RED LOAM FROM KASARAGOD (KERALA)—COMPOSITION (OVEN-DRY BASIS)

Depth (in cm)	0–30	30–60	60–90	90–120	120–150	150–180
Total analysis						
N (%) ..	0.042	0.029	0.031	0.030	0.025	0.024
CaO (%) ..	252	0.266	0.280	0.238	0.238	0.280
MgO (%) ..	0.078	0.078	0.108	0.096	0.078	0.120
K_2O (%) ..	0.3424	0.3510	0.3764	0.3249	0.3552	0.3895
P_2O_5 (%) ..	0.0786	0.0649	0.0679	0.0664	0.0679	0.0633
Available						
K_2O (%) ..	0.0032	0.0043	0.0046	0.0070	0.0032	0.0054
P_2O_5 (%) ..	0.0027	0.0010	0.0011	0.0010	0.0009	0.0009
Exchangeable						
T.E.C. ..	1.8	1.6	1.4	1.4	1.56	1.6
Ca ..	1.3	1.1	1.3	1.1	1.2	1.2
Mechanical analysis						
Coarse sand (%) ..	75.34	74.59	73.85	71.51	74.28	73.72
Fine sand (%) ..	4.47	4.27	4.34	4.45	3.69	3.89
Silt (%) ..	2.0	2.4	2.05	2.25	3.70	2.50
Clay (%)	15.60	16.55	17.55	18.55	15.60	17.50

APPENDIX 24. 'KARI' SOIL (PEATY SOIL) FROM KUTTANAD AREA (KERALA STATE, NEAR THOTTAPALLY SPILLWAY)—COMPOSITION (OVEN-DRY BASIS)

Soil depth 10 cm

pH	5.3	Per cent
Insoluble silica	79.4	"
Soluble silica	0.14	"
Soluble sesquioxides	0.45	"
Fe_2O_3	0.29	"
Al_2O_3	0.16	"
Total P_2O_5	tr.	"
Available P_2O_5	Nil	"
CaO	0.203	"
MgO	0.250	"
K_2O	0.206	"
Available K_2O	0.012	"
Organic matter	14.58	"
N	0.199	"

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INDEX

A

Acid soils, and their amendments, 253–58; treatment for, 254

Acidic soils, 254

Acidity, causes of, 253; correcting of, 254–58

ADCO process, 87

Aeration for micro-organisms, 76

Alfalfa, control of zinc deficiency and excess in, 166; molybdenum deficiency in, 189

Algae, blue-green, 242–51

Algal inoculants, 240–52

Alkali soils, amendments for, 265–72

Alkaline soils, saline and, 44–46

Alluvial soils, 42–43

Almond, control of zinc deficiency and excess in, 166

Alsike, molybdenum deficiency in, 189

Aluminium sulphate, as soil amendment, 272

Amide fertilizers, 133–39

Ammonia, anhydrous, 129–30; fertilizers of, 129–32

Ammonia-nitrate fertilizers, 132

Ammonium chloride, 131; criterion for selection of, 137; manufacture of, 131

Ammonium nitrate, 132; criterion for selection of, 137; manufacture of, 132; suitability of, 136

Ammonium phosphate, manufacture of, 131

Ammonium sulphate, 130–31; criterion for selection of, 137; manufacture of, 130; suitability of, 135

Ammonium sulphate-nitrate, 132; criterion for selection of, 137; manufacture of, 132; suitability of, 135

Anhydrous ammonia, 129–30; criterion for selection of, 137

Apple, boron deficiency in, 183; control of zinc excess and deficiency in, 166; copper deficiency in, 177; iron deficiency in, 180; manganese deficiency in, 171; molybdenum deficiency in, 190; zinc deficiency in, 164

Application of fertilizers, 195–210; methods of application, 198–206; of manures and fertilizers, 275–76; principles of efficient utilization, 195–98; spraying of fertilizer solutions, 209–10; time of application, 206–9

Apricot, copper deficiency in, 177

Arhar, manuring of, 311

Artificial farmyard manure, 87–90; manurial value of, 88–90; preparation of, 88

Assam, green-manure crops of, 54; liming of soil in, 263

Azotobacter, 14; inoculation with, 240

B

Bacteria, fixing nitrogen, 14; isolation of, 225–26

Bacterial, soil inoculants, 222–40

Bajra, manuring of, 305–6

Banana, manuring of, 281–83

Band placement, of fertilizer, 203–4

Bangalore Method, for composting, 93–95

Bangar soil, 42

Barley, boron deficiency in, 182; manganese deficiency in, 169; manuring of, 301–2; molybdenum deficiency in, 187; zinc deficiency in, 164; zinc excess in, 166

Basic slag, 255; manufacture of, 143–44; suitability of, 121

Bean, control of zinc deficiency and excess in, 166; manganese deficiency in, 177; molybdenum deficiency in, 190

Ber, manuring of, 285

Berseem, manurial requirements of, 337

Bhabar, 43

Bhate, 38

Bhindi, manuring of, 288

Bidi tobacco, 334–35

Bihar, green-manure crops of, 54; liming of soil in, 263

Biological effects, of liming soil, 260

Biological fuel gas, and slurry, 103–104

Bitter gourd, manuring of, 288

Black cotton soil, 40–42

Black gram, manuring of, 310–11

Blood, dried, 112

Bloom algae, as manure, 250

Blue pine, 43

Blue-green algae, 242–51

Bone-meal, and bones, 109–11; manufacture of, 141; suitability of, 144–45

Bones, and bone-meal, 109–11

Boron, control of deficiency of, 185–86; cultural practices, 184; functions of, 23; as plant nutrient, 18; response to application of, 186–87; role in plant metabolism, 160; soil conditions influencing availability of, 184; symptoms due to deficiency of, 30–31

Brassica crops, iron deficiency in, 180

Broad bean, boron deficiency in, 183; molybdenum deficiency in, 190

Broadcasting, 199–200

C

Cabbage, boron deficiency in, 181; copper deficiency in, 176; manuring of, 286

Calcium, function of, 22; as plant nutrient, 17; symptoms due to deficiency of, 29

Calcium cynamide, manufacture of, 133; suitability of, 137

Calcium hydroxide, 255

Calcium metaphosphate, manufacturing of, 143; suitability of, 145–46

Calcium nitrate, manufacture of, 128–29; suitability of, 134

Calcium oxide, 255

Caliche, 126

Calotropis gigantea, as green-leaf manure, 50

Capping method, 266

Carbon, function of, 19–20; as a plant nutrient, 12–13

Carnallite, 17

Carrots, copper deficiency in, 176; molybdenum deficiency in, 189

Castor, manuring of, 314–15

Castor cake, as manure, 108

Cauliflower, boron deficiency in, 181; manuring of, 286; molybdenum deficiency in, 188

Cereals, iron deficiency in, 179; symptoms of manganese deficiency in, 31

Chalk, 256

Char soil, 42

Chemical, tests for soil fertility, 211–12

Cherry, control of zinc deficiency and excess in, 166; iron deficiency in, 180; manganese deficiency in, 172

Chewing tobacco, 332–33

Chopan soil, 41

Cigar tobacco, 332–33

Citrus, boron deficiency in, 181; control of zinc deficiency and excess in, 166; copper deficiency in, 32, 176; iron deficiency in, 180; manganese deficiency in, 28, 172; manuring of, 278–81; molybdenum deficiency in, 189; zinc deficiency in, 164; zinc excess in, 166; symptoms of calcium deficiency in, 29; symptoms of nitrogen deficiency in, 27; symptoms of phosphorus deficiency in, 27; symptoms of potassium deficiency in, 28

Classification, of fertilizers, 123; of nitrogenous fertilizers, 124–26; of phosphatic fertilizers, 139–40

Claude-Haber ammonia synthesis, 129–30

Climate, effect on manufacture of fuel gas of, 105; for green manuring, 51; soils and, 34–46

Cluster bean, manuring of, 289

Cobalt, 161

Coconut cake, as manure, 108

Coffee, manganese deficiency in, 171; zinc deficiency in, 164

Compost, 190–95; of farm wastes, 90; manurial value of, 95; of nightsoil, 118–22; preparation of, 118–22; town, 101–103

Composting, essentials for, 119–20

Concord grapes, molybdenum deficiency in, 190

Conditioners, fillers and, 151

Congelo, 126

Congo-red agar medium, 226

Contour farming, 251

Copper, 175–79; control measures for deficiency in, 178; functions of, 23; as plant nutrient, 19; soil condition and availability of, 177; symptoms due to deficiency of, 31

Copper sulphate, application of, 178–79

Corchorus spp., *see* jute

Corn, phosphorus deficiency symptoms in, 27; zinc deficiency in, 164

Costra, 126

Cotton, boron deficiency in, 182; calcium deficiency symptoms in, 29; magnesium deficiency symptoms in, 28; manganese deficiency symptoms in, 31, 171; manuring of, 317–20; nitrogen deficiency symptoms in, 27; phosphorus deficiency symptoms in, 27; response to green manure, 56, 57; sulphur deficiency in, 22; zinc deficiency in, 164

Cowpea, manurial requirements of, 336

Crop(s), effect of lime on, 263–65; manuring of, 275–339; role of plant nutrients in, 11–33

Crop growth, function of nutrients in, 19–24; nutrient supply and, 24–26

Crotalaria spp., as green-manure crop, 48, 58

Cucumbers, manganese deficiency in, 171

Cucurbits, molybdenum deficiency in, 189

Culture, of bacteria, 225–36; of soil, 227

Cyamopsis tetragonoloba, as green-manure crop, 50, 58

D

Dabar soil, 46

Decomposition of farmyard manure, 73–80; of green manure, 52

Deep cultivation method, 239

Deficiency symptoms, 26–32

Desert soil, 44

Dhaincha, as green-manure crop, 48–49, 58; nitrogen added by, 59

Diammonium phosphate, 16, 126; criterion for selection of, 139; manufacture of, 144; suitability of, 136–37, 146

Dicalcium phosphate, manufacture of, 144; suitability of, 146

Distribution and marketing of fertilizer, 156–59

Dolichos biflorus, *see* horse gram

Dorsa soil, 38

Drill placement, 201–203

Dubba soil, 69

Dwarf French Bean, molybdenum deficiency in, 190

E

Egg-plant, copper deficiency in, 175

Electrolytic process, for manufacturing triple phosphate, 143

Elephant grass, manuring of, 338

Erosion, of soil, 198

Excreta, human, 114; liquid, 70–71; solid, 69–70

F

Faeces, human, 114

Farmyard manure, 15, 68–90; artificial, 87–90; composition of, 68–73; decomposition of, 73–80; method of preparation of, 83–85; micro-organisms in, 73–79; synthetic, 87–90; use and effect of, 85–87; value and functions of, 80–83

Ferrous sulphate, 149

Fertility, assessment of, 211–17; of soil, 211–12

Fertility maps, 217

Fertilizer(s), amide, 133–39; ammonia, 129–32; ammonia nitrate, 132; application of, 195–210, 275–76; characteristics of, 123–24; classification of, 123, 124–26, 139–41, 146–47; distribution of, 156–59; grades and ratios of, 124; marketing of, 156–59; materials of, 124;

mixtures of, 150–55; nitrogen, 124–29; phosphatic, 139–46; potassic, 146–49; quality control of, 155–56; time of application of, 196; valuation of, 159

Fertilizer mixtures, 150–55

Fertilizers, 123–59; fertilizer mixtures, 150–55; general, 150–51; marketing and distribution, 156–59; nitrogen fertilizers, 124–39; other fertilizing materials, 149–50; phosphatic fertilizers, 139–46; quality control, 155–56; valuation of fertilizers, 159

Field crops, manuring of, 289–321

Fillers and conditioners, 151

Fish manure, 111

Flax, boron deficiency in, 183; copper deficiency in, 176; manganese deficiency in, 171; molybdenum deficiency in, 189; zinc deficiency in, 164

Flowering plants, manganese deficiency in, 171

Flue-cured tobacco, 331–32

Fodders and grasses, manuring of, 335–339

Food supply, for micro-organisms, 75

Forest, and hill soils, 43–44

Fruit trees, deciduous, 28

Fruits, manuring of, 275–86

Fuel gas, 104–106

G

Garden bean, zinc deficiency in, 164

Garden pea, zinc deficiency in, 164

Garlic, manuring of, 287

Gas, fuel, 104–106

Gliricidia maculata, as green-leaf manure, 50; as green-manure crop, 50

Gooseberries, manganese deficiency in, 172

Gossypium spp., *see* cotton

Grain sorghums, iron deficiency in, 179

Gram, manuring of, 309

Grape, deficiency in, 182; control of zinc deficiency and excess in, 166; molybdenum deficiency in, 190

Grass, manganese deficiency in, 170; manuring of, 335–39

Green-leaf manuring, 50–51

Green-manure crops, in Assam, 54; in Bihar, 54; decomposition of, 52; of different regions, 54; in Kashmir, 54; in Madhya Pradesh, 54; in Maharashtra, 54; in rotation with other crops, 66–67; sowing time for, 52; turning-in of, 52; in Uttar Pradesh, 54; in West Bengal, 54

Green gram, manuring of, 311

Green manuring, 50–51; components of, 58; response of

crops, 54; soil structure, effect of, 60–66; for sugarcane, 322–24; techniques of, 51–54

Grey speck disease in tobacco, 31

Groundnut, manuring of, 312–14

Groundnut cake, as manure, 108

Guano, 111–12

Guar, as green-manure crop, 50; manurial requirements of, 337

Guava, manuring of, 284

Gypsum, deposit of, 17; as fertilizer, 149; requirements of soils, 273–74; as soil amendment, 265–71

H

Hidden deficiencies, 162

Hill soils, 43–44

Hoffer's alkaline medium, 226

Hoof- and horn-meal, 112

Horse gram, as green-manure crop, 50

Horticultural crops, manuring of, 275–89

Hukka tobacco, 333–34

Husks and hulls, as manure, 113

Hyderated lime, 255

Hydrogen, as plant nutrient, 136, function of, 20

I

Indigo, as green-manure crop, 50

Indigofera teysmanni as green-leaf manuring, 51

Indore Method, for composting, 90–93, inoculants of soil, 222–52

Inoculation, with *Rhizobium*, 222–24

Ipomoea carnea, as green-leaf manure, 51

Iron, 179–81; correcting deficiency in, 180; function of, 23; influence of soil conditions on, 180; in plant metabolism, 160; as plant nutrient, 18; symptoms due to deficiency of, 31

Iron sulphate, as soil amendment, 272

J

Jowar, manuring of, 304–5

Juglans regia, *see* walnut

Jute, manuring of, 320–21

K

Kainite, 17

Kakri, manuring of, 288

Kallar, 44

Kanhar soil, 38

Kankar, 41

Karanj cake, as manure, 108

Kari soil, 45

Kashmir, green-manure crops of, 54

Kera, 298

Khadar, 42

Kheera, manuring of, 288

Khesari, manuring of, 310

Kulthi, as a green-manure crop, 50

L

Lady's finger, manuring of, 288

Laterite and lateritic soils, 39–40

Latrines, construction and uses of, 115–18

Law of Diminishing Returns, 290

Law of the Minimum, 290

Law of Restitution, 289

Legume bacteria, isolation of pure culture of, 225–26

Legumes, symptoms due to deficiency of boron, iron, magnesium, manganese, molybdenum and sulphur in, 28–32

Leguminous plants, 14, 335; nitrogen fixed by, 14–15

Lime, 258

Limestone, 254–55; fineness of, 258–59

Liming materials, of by-products, 256

Linseed, copper deficiency in, 176; manuring of, 315–16

Linum usitatissimum, *see* flax

Liquid excreta, in farmyard manure, 70–71

Litchi, manuring of, 284–85

Litmus milk, 226

Litter, 71–73

Localized placement, of fertilizer, 200–201

Long melon, manuring of, 288

Loquat, manuring of, 285

Lucerne, 15; boron deficiency in, 176; manurial requirements of, 338; molybdenum deficiency in, 189

Lycopersicon esculentum, *see* tomato

M

Madhya Pradesh, green-manure crops of, 54

Magnesium, 160; function of, 22; as plant nutrient, 17; symptoms due to deficiency of, 28

Magnesium sulphate, 149

Maharashtra, green-manure crops of, 54

Mahua cake, as manure, 108

Maize, boron deficiency in, 182; copper deficiency in, 175; manganese deficiency in, 170; manuring of, 302; molybdenum deficiency in, 187; symptoms due to deficiency of calcium, magnesium, potassium and zinc, 28–31

Malus sylvestris, *see* apple

Manganese, availability of, 172; correction of deficiency and excess in, 173; function of, 23; as micro-nutrient, 169–74; in plant metabolism, 160–61; as plant nutrient, 18; response to, 173; symptoms due to deficiency of, 31

Manganese sulphate, 150

Mango, manuring of, 276–78

Manufacture of nitrogenous fertilizers, 126–29; of phosphatic fertilizers, 139–46; of potassic fertilizers, 146–49

Manure(s) (*see also* farmyard manure), application of, 275–76; bloom algae as, 250; fish, 111; green, 47–67; other organic, 68–122; seaweed as, 251–52

Manurial value, of artificial farmyard manure, 90; of compost, 94–95

Manuring of crops, 275–339; *arhar*, 311; *bajra*, 305–6; barley, 301–2; black gram, 310–11; castor, 314–15; cotton, 317–20; field crops, 289–321; fodders and grasses, 335–39; fruits, 276–86; gram, 309; green gram, 311; groundnut, 312–14; horticultural crops, 275–89; *jowar*, 304–5; jute, 320–21; *khesari*, 310; linseed, 315–16; maize, 302–4; mustard, 316–17; paddy, 290–96; peas, 310; potato, 325–30; pulses, 307–12; *ragi*, 306–7; rape and mustard, 316–17; sesamum, 315; sugarcane, 322–24; tobacco, 330–35; vegetable crops, 286–89; wheat, 296–301

Marketing and distribution of fertilizers, 156–59

Marshy soils, peaty and, 46

Matasi soil, 38

Medicago sativa, *see* alfalfa and lucerne

Metabolism, role of micronutrients in, 160–62

Methra, manurial requirements of, 338

Micro-elements, effects of, 162–94

Micronutrients, 160–94; boron, 181–87; copper, 175–79; effects of micro-elements, 162–94; iron, 179–81; manganese, 169–74; molybdenum, 187–94; role in plant metabolism, 160–62; zinc, 163–69

Micro-organisms, in farmyard manure, 73–79; growth requirements of, 73–79

Milk tests, 226

Moisture, of micro-organisms, 76; in soil, 197–98

Molybdenum, function of, 24; measures for correcting deficiency in, 192; as micronutrient, 187–94; as plant nutrient, 19; response to application of, 192; soil conditions related to availability of, 190–91; symptoms due to deficiency of, 32

Monoammonium phosphate, 126; criterion for selection of, 139; manufacture of, 144; suitability of, 136–37; 146

Mung, 15; as green-manure crop, 49

Murrum, 40

Musk-melon, manuring of, 288

Mustard, manuring of, 316–17

N

Napier grass, manurial requirements of, 338

Neem cake, as manure, 108

Nicotiana spp., *see* tobacco

Night-soil, 96–103, 114–18; compost of, 118–22; and urine, 114–18

Nitrogen, addition by legumes, 59; blue-green algae fixing, 242–51; function of, 20–21; organisms fixing, 14; symptoms due to deficiency of, 27

Nitrogen fertilizers, 124–39

Nitrogen fixation, by blue-green algae, 242–51

Nitrogen, function of, 20–21; as plant nutrient, 14–16; symptoms due to deficiency of, 27

Nitrogenous fertilizers, effect on paddy of, 292–96; effect on wheat of, 296

Nutrient supply, and plant growth, 24–26

Nutrients, 11–33; crop growth and supply of, 24–26; deficiency symptoms, 26–32; function of, 19–24; interaction of, 25–26; major, 12–17; minor, 12, 18, 19

O

Oates, manganese deficiency in, 169; manurial requirements of, 338; molybdenum deficiency in, 187; zinc deficiency in, 164

Oil palms, boron deficiency in, 183

Oilcake, as manure, 106–109

Okra, manuring of, 288

Onion, boron deficiency in, 183; copper deficiency in, 175; manganese deficiency in, 171; manuring of, 287

Organic manures (others), 68–122; artificial or synthetic farmyard manure, 87–90; biological fuel gas and slurry, 104–106; bones and bone-meal, 109–11; compost, 90–95; farmyard manure, 68–90; fish manure, 111; guano, 111–12; night-soil and sewage, 96–103; night-soil and urine, 114–18; oilcakes, 106–109; other manures, 112–14

Orissa, green-manure crops of, 54; liming of soil in, 263

Oxygen, function of, 20; as plant nutrient, 13

P

Paddy, manuring of, 290–96

Paira, 308

Papaya, manuring of, 283

Para grass, manurial requirements of, 339

Parwa soil, 39

Peach, boron deficiency in, 183; control of zinc deficiency and excess in, 166; copper deficiency in, 177; manganese deficiency in, 172; zinc deficiency in, 164

Peanuts, manganese deficiency in, 171

Pears, boron deficiency in, 183; control of zinc deficiency and excess in, 166; copper deficiency in, 177; iron deficiency in, 180; manganese deficiency in, 172

Peas, boron deficiency in, 182; copper deficiency in, 176; manganese deficiency in, 171; manuring of, 287, 310; molybdenum deficiency in, 190

Peaty, and marshy soils, 46

Pepper, copper deficiency in, 196

Phaseolus spp., 15; as green-manure crop, 49
  mungo, see black gram
  trilobus, as green-manure crop, 49

Phosphatic fertilizers, classification and importance of, 139–46; manufacture of, 141–44; suitability of, 144–46

Phosphobacterin, inoculation with, 240

Phosphorus, function of, 21; as plant nutrient, 16–17; symptoms due to deficiency of, 27

Physiology, of blue-green algae, 242

Pillipesara, nitrogen fixed by, 59

Pineapple, manganese deficiency in, 172

Pisum sativum, see peas and garden pea

Plant metabolism, role of micronutrients in, 160–62

Plough-sole placement, of fertilizer, 203

Plums, boron deficiency in, 183; copper deficiency in, 177; iron deficiency in, 180; manganese deficiency in, 172

Pongamia glabra, as green-leaf manure, 50

Pora, 298

Pot-herbs, manuring of, 287

Potash, as plant nutrient, 16

Potassic fertilizers, 146–49

Potassium, function of, 21–22; symptoms due to deficiency of, 28

Potassium chloride, manufacturing of, 147; suitability of, 148

Potassium sulphate, manufacture of, 147; suitability of, 148

Potato, boron deficiency in, 181; iron deficiency in, 180; manganese deficiency in, 170; manuring of, 325–30; molybdenum deficiency in, 188; symptoms due to deficiency of potassium, zinc, copper, phosphorus, magnesium, calcium, manganese, 26–32; zinc deficiency in, 165

Poudrette system of, disposal of night-soil, 96–98

Poultry manure, 69

Poverty adjustment, 24

Pressmud, as liming material, 257; as manure, 113; as soil amendment, 271

Prunus, copper deficiency in, 177

Pulses, manuring, of, 307–12

Pumpkin, manuring of, 288

Punjab, green-manure crops of, 54; liming of soil in, 264

Pusa Giant Napier, manurial requirements of, 339

Q

Quick lime, 255

R

Radish, boron deficiency in, 182; molybdenum deficiency in, 189

Ragi, manuring of, 306–7

Rape, manuring of, 316–17

Rapeseed cake, as manure, 108, 109

Raphanus sativus, see radish

Raspberries, manganese deficiency in, 172

Raw sewage, 98–99

Reclamation, of soils, 272–73; of usar soils, 250–51

Red soils, 37–39

Regur, 40–41

Reh, 44

Rhizobium, efficiency of, 227; inoculation with, 222–24

Rhodes grass, manurial requirements of, 339

Rice, response to green-manuring, 54, 55; role of blue-green algae in fields, 245–49; *see also* paddy

Rock phosphate, 16; manufacture of, 141; suitability of, 145

Role of plant nutrients in crop production, 11–33; deficiency symptoms, 26–32; function of nutrients in crop production, 19–24; nutrient supply and crop growth, 24–26; nutrients, 11–19

Roselle, molybdenum deficiency in, 189

Rotation, green-manure crops for, 66–67

Rubber, manganese deficiency in, 171; molybdenum deficiency in, 190

S

Saline, and alkaline soils, 44–46

Saline-alkali soils, amendments in, 272–73; reclamation of, 65

Sarson cake, as manure, 108

Savoy cabbage, molybdenum deficiency in, 189

Saw-dust, 73

Seaweed, as manure, 251–52

Senji, manurial requirements of, 338; nitrogen fixed by, 59

Sesamum, manuring of, 315

Sesbania spp., as green-manure crop, 48–49; nitrogen fixed by, 49; *aculeata*, see *S. bispinosa*, as green-manure crop, 48, 58; as green-leaf manuring, 51

Sewage, and night-soil, 96–103; raw, 98–99

Sewage effluent, 99–101

Sewage sludge, 101

Side-dressing, 199

Silkworm wastes, wool and, 112

Slag, basic, 255; blast furnace, 256; furnace, 256; electric furnace, 256

Slaked lime, 255

Slaughter-house waste, 112

Sludge, sewage, 101

Slurry, biological fuel gas and, 103–104

Sodium chloride, 149

Sodium nitrate, manufacture of, 126–28; suitability of, 133–34

Soil(s), acidic, 253–54; agencies for collecting samples of, 214–15; amendments for, 253–74; amendments for alkali, 265–72; analysis of, 215; assessment of fertility of, 211–21; beneficial effects of lime on, 259–60; collection of samples of, 213–14; effects of liming on, 259–60; exchange capacity of, 198; fertility of, 211–12; gypsum requirements of, 273–74; lime requirements of, 261–62; moisture in, 197; physical condition of, 260; procedure for collecting samples of, 213; testing of, 212–16; testing system, 212–16; transport of samples of, 215

Soil amendments, 253–74; acid soils and their amendments, 253–58; amendments for alkali soils, 265–72; gypsum requirements of soils, 273–74; lime, 258–65; soil amendments in alkali-saline soils, 272–73

Soil conditions, influencing availability of micro-elements, 161–62

Soil culture, 227

Soil inoculants-bacterial and algal, 222–52; algal inoculants, 240–52; bacterial inoculants, 222–40; blue-green algae capable of fixing nitrogen, 242–51; culture, 225–36; mass growing of micro-organisms, 236–40; seaweed as manure, 251–52

Soil fertility assessment by soil-testing system, 211–21; soil fertility, 211–12; soil testing, 212–16; soil testing kits, 216–17

Soil medium, 227

Soil testing, 212–16

Soil-testing kits, 216–17

Soil-testing laboratories, methods used in, 215

Soil-testing system, 212–16

Soils and climate, 34–46

Sowing time, for green manures, 52

Soybean, 15

Spinach, manganese deficiency in, 170; molybdenum deficiency in, 188

Spot placement, of fertilizer, 204–205

Squash, zinc deficiency in, 165

Strain variation, in blue-green algae, 242

Strawberries, manganese deficiency in, 172

Sugarcane, boron deficiency in, 182; manuring of, 322–24; response to green-manuring, 55, 56

Sugar-beet, zinc deficiency in, 165

Sulphur, as plant nutrient, 17; function of, 22; as soil amendments, 271; symptoms due to deficiency of, 32

Sulphuric acid, 272

Summer vegetables, manuring of, 288–89

Superphosphate, distribution of, 157; manufacture of, 141–42; suitability of, 145

Sweet-potato, manganese deficiency in, 170; boron deficiency in, 183

Symptoms, deficiency, 26–32

Synthetic farmyard manure, 87–90

T

Tamil Nadu, liming of soil in, 263

Tannery refuse, 113

Temperate fruits, 285

Tephrosia candida, as green-leaf manure, 51; *purpurea*, as green-leaf manure, 50, 51

Terai, 43

Testing of soil, 212–16

Tobacco, boron deficiency in, 182; copper deficiency in, 175; 'grey speck disease' in, 31; manuring of, 330–35; manganese deficiency in, 170; molybdenum deficiency in, 188; symptoms due to deficiencies of potassium, zinc, boron, manganese, iron, copper and sulphur, 28–32; zinc deficiency in, 165

Tomato, boron deficiency in, 182; control of zinc deficiency and excess in, 166; copper deficiency in, 175; iron deficiency in, 179; manganese deficiency in, 170; molybdenum deficiency in, 187; zinc deficiency in, 165

Top-dressing, 199

Town compost, 101–103

Toxicity, of micro-elements, 162

Transport, of soil samples, 215

Treatment, for acid soils, 254

Trigonella foenum-graecum, 56; *see* also *methi*

Triple-superphosphate, manufacture of, 142–43

Tur, see *arhar*

Turning-in, of green-manure crop, 52

U

Unslaked lime, 255

Urea, 133; criterion for selection of, 137; manufacture of, 133; suitability of, 137

Urine, composition of, 70–71; and night-soil, 114–18

Usar soils, 45; reclamation of, 250–51

Uttar Pradesh, green-manure crops of, 54

V

Vegetables, phosphorus deficiency symptoms in, 28; manuring of, 276, 286–89

W

Wardha type latrine, 115–18

Water-melon, manuring of, 288

Water seal type latrine, 117–18

West Bengal, green-manure crops of, 54; liming of soil in, 265

Wet process, 142

Wheat, boron deficiency in, 182; copper deficiency in, 175; manganese deficiency in, 169; manuring of, 296–301; molybdenum deficiency in, 187; response to green-manuring, 53, 54

Winter vegetables, manuring of, 286–88

Wood-ash, 257
Wood-shavings, 73
Wool, and silkworm wastes, 112

Y

Yeast-extract congored medium, 226
Yield of crops, effect of lime on, 263

Z

Zinc, 163–69; control of deficiency and excess in, 166–67; deficiency of, 163; excess of, 166; function of, 23; in plant metabolism, 160–61; as plant nutrient, 18; response to application of, 167–69; symptoms due to deficiency of, 30
Zinc sulphate, 150

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